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OLDMAN RIVER DAM

OLDMAN RIVER DAM

DESIGN REPORT

VOLUME 2 of 3

**SEPTEMBER 1988
(UPDATED JUNE 1989)**

DAM AND DYKE CONTRACT
DESIGN REPORT

APPENDIX B

SHEAR STRENGTH

SEPTEMBER 1988

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B1.0 INTRODUCTION

B1.1 OBJECTIVES

This report summarizes the findings of all geological and geotechnical site investigations and laboratory testing regarding the shear strength aspects of bedrock, overburden and fill materials for the dam, dyke and spillway, in particular the design assessment carried out to evaluate the shear strength of seams within the bedrock foundation.

This information is used to determine the design seams and their shear strength parameters as used in the stability analyses presented in Appendix C and D.

B1.2 SCOPE

Appendix B is subdivided into two basic parts. The first part consists of Sections B2.0 to B15.0 which cover all the geological and geotechnical site investigations, laboratory testing and design assessment of shear strength along the seams in the bedrock foundations of the dam and spillway.

Section B2.0 presents a summary of the site conditions and discusses the general principles of shear strength behaviour of discontinuities in rock. Finally, the methodology used in obtaining a geological and geotechnical assessment of the foundation shear strength to be used in the design of the major structures is described.

Section B3.0 and B4.0 respectively describe the regional and site bedrock geology. Much of this data was previously described in the Preliminary Engineering Report (1986).

Section B5.0 summarizes the field investigations carried out in 1987 specifically for the geological assessment of the seams exposed in construction excavations at the site.

Section B6.0 describes the assessment of the data in the drill hole and shaft logs obtained from all the site investigations to date.

Section B7.0 summarizes the results of the assessments carried out in Sections B5.0 and B6.0. The seams are described according to the location and exploratory tool used.

Sections B8.0, B9.0, B10.0 and B11.0 summarize the geological assessment of the seams as they occur in situ. The seams are described in terms of their correlation with certain carbonaceous marker beds in the bedrock stratigraphy, their physical characteristics, continuity and thickness and finally the roughness and thickness components of shear strength.

Section B12.0 describes in detail the results of the laboratory direct shear testing of samples taken from the seams.

The final geotechnical assessment of the shear strength along the seams is described in detail in Section B13.0. Here the results of the field investigations and laboratory testing are combined to identify the continuous design seams for each structure and their design shear strength.

The first part concludes with a discussion of the shear strength along the bedding and the cross-bedding shear strength, respectively in Section B14.0 and B15.0.

The second part consists of Sections B16.0 to B18.0. Section B16.0 presents all the summary data on the material properties used in the static and dynamic finite element analyses for the dam structure, including overburden, bedrock, impervious core and granular shell materials.

Sections B17.0 and B18.0 include the cyclic testing for the compacted till, river alluvium and seam material.

B1.3 TERMINOLOGY

The following terminology applies to the usage in this appendix .

- | | |
|----------------|---|
| Asperity | - A single sloping surface which deviates from the planarity of a given surface and causes 'roughness'. |
| Asperity Angle | - The angle between the plane of a given surface and the slope of the line defining the asperity. |
| Base Length | - The distance along the line of inclination for which the roughness angle measurement applies. |
| Conformable | - Strata or groups of strata lying one above another in parallel order.

- When beds or strata lie upon one another in unbroken and parallel order and this arrangement shows that no disturbance or deviation has taken place at the locality while their deposition was going on. |
| Continuity | - The measurable distance within the rock mass, over which a given geological feature exists. |

Continuous	- Proven or inferred to extend unbroken over a given length. - For a given structure, proven or inferred to extend over a length equal to or greater than the structure dimensions.
Design Seam	- Continuous seam which due to its location and value of effective angle of shearing resistance is important to the stability of a structure.
Design Shear Strength	- The value of the effective angle of shearing resistance of the design seam.
Dip	- Maximum inclination of a planar feature with respect to a horizontal plane. Dip is at right angles to the strike.
Dip Direction	- Azimuth of the line along the dip.
Disconformity	- Unconformity between parallel strata, e.g., with strata below not dipping at an angle to those above.
Discontinuous	- Proven or inferred to be broken or not to be continuous over a given length. - Proven or inferred not to be continuous over a length equal to or greater than the structure dimensions.
Discontinuity	- A natural parting in a rock mass separating intact rock, e.g., joint, bedding plane, fracture.
Infilling	- Material found between the wall rocks of a discontinuity.
In Situ Shear Strength	- The peak shear strength measured in the laboratory which is interpreted to represent in situ state shear strength.

Marker Bed	- A rock unit of wide areal extent which has some unique feature which clearly distinguishes it from the rest of the rock mass.
Peak Shear Strength	- Maximum shearing resistance measured when material is first sheared.
Planes	- Refers to the infinitely thin, theoretical surface defining any discontinuity. It is not necessarily truly 'planar'.
Residual Shear Strength	- Minimum shearing resistance obtained after material is sheared to very large strains such that the shear strength then developed is at a constant minimum strength state.
Roughness	- Scale-dependent term describing the deviation from planarity of a given surface. Measurements are usually expressed in degrees of angular deviation over a given base length.
Seam	- Discontinuity filled with material which is weaker than the adjacent wall rock.
Seam Surface	- The flattest possible surface of greatest continuity within the seam.
Shear Surface	- The surface along which there has been relative shear displacement.
Strike	- Direction of a horizontal line on an inclined surface. Strike is at right angles to the dip.
Structural Feature	- General name given to discontinuities exhibiting characteristics related to shear deformation.
Thickness (of a seam)	- Measured perpendicular to the wall rock surface.
Unconformable	- Not succeeding the underlying strata in immediate order of age and parallel position.

Unconformity

- A surface of erosion that separates younger strata from older rocks.

Wall Rock
Surface

- The contact between the seam and the adjacent intact rock.

Wall Rock

- The intact rock adjacent to the seam.

B2.0 FOUNDATION SHEAR STRENGTH

B2.1 SITE CONDITIONS

The Oldman River dam site is located in a series of subhorizontally bedded, sedimentary rocks, including sandstone, siltstone and claystone. While most of the bedrock in the valley bottom and abutments is relatively strong, some parts of the bedrock are characterized by numerous, very thin seams which are usually filled with clay/silt and/or rock fragments. The seams are subparallel to the bedding and may approach a planar condition. The seams are relatively continuous and occur at contacts of relatively weak and strong rocks. It is probable that these seams are the result of shearing parallel to beds during valley rebound and the formation of the Alberta Syncline.

Most of the seams in the foundation have developed as the adjacent strata underwent relative displacement. As relative displacement occurs on a seam, the shear strength tends to decrease from the peak strength value to a value approaching that of the residual state. Depending on the strength and thickness of the original beds, a pulverized infilling may be generated in situ during shearing; this infilling facilitates the observation and identification of the seam in situ.

Since the shear strength or resistance available along the seams is significantly less than that across other intact bedding planes, the seams are generally among the weakest planes in the foundation. Therefore, the seams are considered significant to the foundation design.

Accordingly, the geological and geotechnical studies of the Oldman dam foundation were concentrated on the assessment of the engineering properties of the seams which ultimately affect the foundation shear strength. In spite of the presence of these planes of relative weakness, there is no evidence of rock mass instability in the general vicinity of the project site. This fact has been taken into account during the design and no instability of the rock slopes at the project site is expected under reservoir operating conditions. In order for a seam to be at its residual shear condition over a large area it would have been subjected to very large shear deformations that are normally associated with mountain building tectonics. Locally the seam may have deformed sufficiently to reduce its shear strength to residual value but such a local area would be small compared to the potential sliding surface controlling the stability of the dam or the spillway.

B2.2 GENERAL PRINCIPLES

The shear behaviour of mated discontinuities where rock-to-rock contact occurs, is very different from that of discontinuities containing infilling of soil-like material. Generally, the total shear strength along a mated discontinuity with rock-to-rock contact is the sum of two main components. (Patton (1961)). The primary component is the residual shear strength obtained from prolonged shearing of smooth surfaces. This value, which can be measured in the laboratory, is an intrinsic minimum shear strength value which is generally controlled by the mineralogy of the sheared material. It is accepted practice in geotechnical design, to add to this basic laboratory test value of the residual shear strength a wall rock roughness component.

The assumption that the insitu shear strength is at its residual state is generally considered to be unnecessarily conservative as rock is very seldom found to have been subjected to such very large strains (Lauga and Taylor (1983), Cornish and Moore (1985), Fell et al (1987), USCE (1970), Barton and Choubey (1977), Barton (1973), Skempton and Petley (1967), Nicholson (1983), Hamel and Spencer (1984), Binnie et al (1967)).

Roughness along mated discontinuities with rock-to-rock contact in a large rock mass is a matter of scale. Along these discontinuities, microscopic roughness due to interlocking mineral grains of the rock walls on either side of the discontinuity may occur. (Jaeger (1970)). Macroscopically, roughness occurring as irregular or wavy undulations (asperities) on the rock wall surface of the discontinuity may be seen. These are physically measurable in terms of inclination and slope distance, or in terms of amplitude and wavelength. Since roughness does not occur in regular wavelike patterns, measurements of inclination and slope distance are usually taken. Roughness measurements are expressed in degrees relative to the dip of the discontinuity. The smallest measurable roughness is termed 'first order' roughness. 'Second order' roughness may be defined as the combination of any two adjacent 'first order' asperities. By simple geometry, the first order roughness is the steepest. When combining any two adjacent values, the resulting average angle is always less than the steepest angle in the group.

Theoretically, a rock wall surface along the discontinuity may be characterized by obtaining higher order roughness measurements over longer base lengths, until some lower

average value is obtained that characterizes the rock wall surface roughness over the lengths affected by structures, such as the dam and spillway.

For mated discontinuities with rock-to-rock contact, the roughness angle is a direct contribution to the shear strength. The shear strength of these discontinuities is given by the expression

$$\tau = \sigma_n \tan (\phi'_r + i)$$

where τ = shear strength of discontinuity
 σ_n = effective normal stress on plane of shearing
 ϕ'_r = Residual angle of shearing resistance
 i = Roughness angle

For sheared discontinuities, as opposed to unsheared discontinuities, the mated nature of the adjacent rock surfaces has been destroyed and the lower roughness of second order, or higher, asperities may reduce the value of i in the above equation. For extensively sheared surfaces, i approaches 0° and the shear strength is governed only by the residual friction angle.

For filled discontinuities, where there is no initial rock-to-rock contact, shear behaviour is more complex. The wall rocks are no longer mated and are separated by an infilling material having its own shear strength behaviour.

Roughness under these conditions can be divided into two types:

- wall rock roughness
- seam roughness

Wall rock roughness cannot contribute directly to the shear strength of the seam as is the case for rock-to-rock contact; however, depending on the thickness of the seam and the in situ natural state of the infilling, some contribution may be possible.

The seam roughness is a measure of the planarity or geometry of a given seam. Over short base lengths within a given seam a hypothetical shear surface will be quite flat.

Since a distinct shear plane may not exist, the overall surface of sliding will be governed by the longer base length roughness of the wall rock confining the seam.

As longer base lengths are used, e.g., tens of metres, within a given seam, the wall rock roughness will approach the value of the seam roughness.

For thicker seams, the seam roughness may be very close to 0° . However, for thinner seams a roughness component may be added to the residual strength value in a manner analogous to that for rock-to-rock contact.

The magnitude of the wall rock roughness contribution for a given seam thickness is difficult to quantify. Theoretically the maximum value would be obtained for no infilling and rock-to-rock contact. This value would decrease to zero at a point where the filling thickness was such that there was no wall rock interaction. However, this relationship is complicated by the behaviour of the filling material itself.

In summary, the total shear strength along a given seam can be determined by summing the residual shear strength value, plus the shear strength component due to the seam roughness, plus shear strength component due to the wall rock roughness (which is thickness dependent), plus a component reflecting the in situ state of the filling material.

The following sections will discuss the details obtained from site wide investigations which lead to an assessment of the shear strength parameters for the few design seams critical to the stability of structures.

B2.3 METHODOLOGY

The study was carried out in the following steps:

1. Identify all seams from site-wide data.
2. Determine those seams which are continuous and are significant for the design.
3. From the measured residual shear strength parameters for each seam, determine representative values of residual shear strength.
4. Add on additional components to account for seam surface roughness, thickness (wall rock roughness) and in situ state of material.
5. Assess and choose 'design seams'.

B2.3.1 Identification of All Seams

An examination of all the field data areally across the site and vertically through the stratigraphic profile enables the selection of a relatively large group of seams which generally represent the weakest planes within the foundation

bedrock. This selection is required for foundation design purposes wherein ultimately the relatively few "design seams" which are critical to the stability of structures, must be identified. In order to expedite the identification of the design seams, the seams were categorized, first on the basis of continuity and secondly on the basis of thickness.

B2.3.2 Determination of Continuous Seams

For any seam to be relevant in the foundation design analysis, it must be shown or inferred either to be present or to be continuous over lengths of the same order as the base of the structure for which the stability is being assessed. It has been found for example that a major portion of the rock containing one of the seams, that otherwise would have had a significant influence on the stability of the dam, has been eroded and infilled with alluvial material. Seams which are shown or inferred to be continuous for lesser lengths can be termed discontinuous and are not significant to the design analysis.

Of the continuous seams identified, a distinction can also be made between thick and thin seams, recognizing that slightly different shear strengths will be assigned to each.

B2.3.3 Determination of Representative Values of Residual Shear Strength

Residual shear strengths measured in the laboratory for a given seam can be expected to show a distribution of values. The scatter of results is variable, depending on the variation of characteristics along the respective seam.

A representative residual shear strength must be selected from the distribution. This value must be a realistic representation of the actual insitu conditions, and, because of uncertainty, it must also be reasonably conservative, i.e., not excessively above the minimum measured residual shear strength. (USCE (1970)). The values chosen have been termed the representative residual shear strengths. Details of this aspect are given in Section B13.0.

B2.3.4 Add-On Components

The total shear strength available along a given seam is generally the sum of the residual shear strength plus the relatively small contributions to shear strength due to seam roughness and thickness. Identification of the relatively thin seams indicates those surfaces where a small shear strength value can be added to the residual value in the final determination of the shear strength value to be assigned to a given seam.

A comparison of the peak (in situ) shear strength, measured in the laboratory, and the final (residual) shear strength on a test-by-test basis for each seam, enables the identification of one further contribution to the shear strength. For example, if none of the measured in situ shear strengths for all tests for a given seam actually show the residual shear strength, i.e., all tests show in situ shear strength in excess of the residual strength, then following commonly accepted practice a small additional shear strength component, known as the in situ state shear strength component, can be added to the representative residual shear strength. (BCHPA (1971), Barton and Choubey (1977)). This component recognizes the fact that, in a rock

mass that has been subjected to shear deformation, not all seams have been sheared to the same degree, nor to the residual value. It also compensates for any in situ effects due to the interaction of the filling material with the wall rock. The selected magnitude of this component must also take into account any further deformation of the rock mass that may take place due to construction activities.

In summary, the final shear strength to be used for a given seam is the sum of the representative residual shear strength, the in situ state shear strength component, the seam roughness component and the seam thickness component.

B2.3.5 Selection of Design Seams

The design seams must be selected from the previously identified site wide population of seams. They must be selected according to specific structures, their relative elevations and the shear strength values characteristic of each of the postulated seams. Details of this selection process are given in Section B13.5. This will identify the individual "design seams" to be used in the stability analysis of a given structure or portion of a structure. The shear strength values used for those critical "design seams" are called "design shear strengths" to differentiate from the shear strength of less critical seams.

Once the design seam and design shear strengths are identified, the foundation design analysis for a given structure follows. It is noted that the stability analyses must take into account the orientation or dip of the design seams relative to the direction of postulated structure movements. It must also take into account that certain

design seams may have been eroded and therefore can be deleted from the analysis. An example of this is in the downstream portion of the river valley bottom where the river down cutting has removed some of the design seams.

The stability analysis is discussed in further detail elsewhere in the report.

The regional geology has been previously described in the Preliminary Engineering Report, Appendix D, of March, 1986. A summary is presented as follows.

The region in which the dam site is located comprises two physiographic regions, the Alberta Plain and the Rocky Mountain Foothills. The dam site is situated on the Alberta Plain approximately 9 km northeast of the edge of the Rocky Mountain Foothills. The area is underlain by gently dipping Upper Cretaceous and Tertiary sedimentary rock units which form a broad, regional synclinal structure called the Alberta Syncline (Douglas (1950) and (1970)).

The syncline comprises the Porcupine Hills formation which forms the core and the underlying Willow Creek formation. The Porcupine Hills Formation is a nonmarine clastic sequence consisting of interbedded sequences of cross-bedded, grey, buff-weathering, ledge-forming, calcareous sandstones with grey to dark grey siltstone and silty claystone mudrocks. The lower contact of the Porcupine Hills Formation is considered to be disconformable.

The underlying Willow Creek Formation is a nonmarine, clastic sequence consisting of interbedded mudrocks and sandstones. The mudrocks consist of green, grey and purplish claystones and siltstones with very occasional bentonite beds. These bentonitic claystones have been found in a few isolated layers towards the base of the formation. (Douglas (1950)). No bentonite or bentonitic material were

found in any of the drillholes that penetrated the Willow Creek Formation at the project site. (UMA/Acres (1986), UMA/Acres (1987)). The sandstones consist mainly of poorly indurated, massively bedded and cross-bedded, fine grained, grey, quartz sandstone; some hard, thin bedded, fine grained layers with calcareous cement are also present. Mudrocks are generally more abundant than sandstones.

The Alberta Syncline was formed during the Rocky Mountain orogeny. The syncline is an asymmetric structure, the axis of which, according to Irish (1967), is about 15 km east-northeast of the dam site and plunges at about 0.30° in the north-northwest direction. The east limb has a very flat dip while the west limb is slightly steeper. The dam site is on the west limb of the syncline. In the site area, the average dip of the west limb as measured from the Porcupine Hills - Willow Creek contact to the fold axis on the map by Irish is estimated to be 0.40° ENE. These dip estimates suggest that the true dip of the strata at the site approaches 0.6° in the NNE direction.

The eastern part of the Rocky Mountain Foothills is characterized by steeply west-dipping strata, repeated by closely spaced, high-angle thrust faults and minor folds. Immediately adjacent to the west of the Alberta Syncline, the deformation was less intense, resulting in steep eastern dips, open folds, and west and east-dipping faults (Douglas (1950)).

With the exception of some minor, local strata dislocations, no faults are known in the immediate vicinity of the dam site; however, thrust faults are present at depth in the

Willow Creek Formation. These faults pre-date deposition of the Porcupine Hills Formation because they do not cross the contact between the Willow Creek and Porcupine Hills Formations (Bossart (1957), Carrigy (1971)).

The region has been repeatedly glaciated and hence the bedrock is mantled with overburden comprising glacial till, glaciofluvial and glaciolacustrine materials. Postglacial sediments include alluvial gravel and sand in terraces and floodplains along the river and stream valleys, colluvium on the valley slopes, and a discontinuous blanket of eolian silt on the upland areas.

B4.0 SITE BEDROCK GEOLOGY

B4.1 STRATIGRAPHY

The rocks exposed at the surface at the dam site belong to the Porcupine Hills formation. At depth is the Willow Creek Formation. For engineering purposes, three major stratigraphic units have been identified at the dam site, as shown in Table B4-1 and on Plates B1, B2, B3 and B4.

TABLE B4-1
DAM SITE STRATIGRAPHY

FORMATION	MAJOR STRATIGRAPHIC UNITS
Porcupine Hills	Upper Mudrock Sequence
	Basal Sandstone Sequence
-----DISCONFORMABLE CONTACT-----	
Willow Creek	Lower Mudrock Sequence

The Lower Mudrock Sequence underlies the Basal Sandstone Sequence throughout the site area at an approximate depth of about 45 m below the river level (at the dam axis). The Lower Mudrock Sequence comprises primarily interbedded claystone, silty claystone, clayey siltstone, and siltstone, and to a lesser extent, silty sandstone and sandstone. Considerable lateral and vertical variation exists within the strata; horizontal continuity of a given rock type at a particular stratigraphic level is, therefore, limited. Facies changes are frequent in the horizontal direction.

Thin, black, carbonaceous claystone bands generally up to 50 cm thick are found in the Lower Mudrock Sequence. The Lower Mudrock Sequence is considered to be a shallow river channel and floodplain type of deposit.

The geological maps of southwest Alberta (Irish (1967)) show that the boundary between the Willow Creek formation and the overlying Porcupine Hills formation should lie in the river banks at the project site. However, the upper contact of the Lower Mudrock Sequence at approximate elevation 1006 m (dam axis) has been tentatively established by palynological studies (Jerzykiewicz and Sweet (1985)) as the top of the Willow Creek Formation.

The Basal Sandstone Sequence extends from elevation 1006 to 1043 m (dam axis) and is divisible into three sections. The upper section, 10 m thick, and the lower section, 13 m thick, consist of uniform, very thickly bedded and very continuous strong sandstone. The central section, 14 m thick, consists primarily of sandstone, but contains several relatively thin subsections of interbedded siltstone and claystone. These have been described in the Preliminary Engineering Report as Structural Units Nos. 1 and 2. The thickness and continuity of these mudrock beds are highly variable. The Basal Sandstone is considered to be a deep channel type deposit. This Basal Sandstone is not actually exposed in the dam foundation area in the valley bottom.

The Upper Mudrock Sequence overlies the Basal Sandstone Sequence and forms the abutments of the dam. This sequence comprises primarily claystone, silty claystone, clayey siltstone, and siltstone, but has considerable thicknesses of silty sandstone and sandstone.

Two unusually thick sandstone channel deposits occur in the Upper Mudrock Sequence. One occurs high in the left abutment and is a maximum of 16 m thick. The second immediately overlies the Basal Sandstone in the downstream dam site area and varies from a maximum of 5 m thick in the left abutment to 18 m in the right abutment; a thin basal layer of this channel sandstone forms the upper most bedrock in the downstream river bed area. These sandstone deposits are considered to be overbank and shallow channel type deposits.

The strata comprising the Upper Mudrock Sequence are similar to those in the Lower Mudrock Sequence in terms of horizontal and vertical variability and horizontal continuity. Similarly, thin, continuous, black, carbonaceous beds exist at regular intervals through the Upper Mudrock Sequence; major carbonaceous beds are nearly site-wide in distribution and can serve as stratigraphic marker beds, while minor carbonaceous beds show lesser areal extent. Calcrete nodules also occur in zones in certain stratigraphic levels in the mudrock; these zones locally serve as marker beds.

In the Preliminary Engineering Report (UMA/Acres (1986)), reference is made to rock units J1 to J11 in describing the strata of the Upper Mudrock Sequence. As described below, a sequence of carbonaceous marker beds has been identified which can be better used for correlation of strata and structural features, hence the J units are no longer referred to. The same applies to units K, L and M of the Basal Sandstone and Lower Mudrock Sequences.

No evidence of bentonite as reported by others to exist in a few isolated thin layers in the 840 m thick Willow Creek formation (Douglas (1950), Hage (1943), Mollard (1985)), was found in the upper 40 m portion of the Lower Mudrock Sequence or any of the rock drilled during the site investigation. There is no record of bentonite or bentonitic shales being found in any part of the Porcupine Hills formation, and none was found at the site. Because of these existing geological reports, particular attention was paid during all phases of the site investigation to this question of the possible presence of bentonitic rocks. The highest level of smectite measured in a sample of claystone exhibiting the highest clay content and plasticity was 6% as determined by x-ray diffraction analysis.

B4.2 BEDDING DIP

Although the dip of the strata at the site is essentially subhorizontal, there is a small detectable upstream dip approaching 0.6° . As mentioned in the Preliminary Engineering Report (UMA/Acres (1986)), this was strongly suggested considering the orientation of the upper and lower geological contact planes of the Basal Sandstone and the corresponding contact planes for the central mudrock section of the Basal Sandstone. The 0.6° dip was also suggested from study of the zones of calcrete nodules in the Upper Mudrock Sequence, although these zones are not as regular in thickness and not as continuous as the above major geological contact planes.

Recent studies, including exploratory and shaft drilling in the spillway area and mapping of the upstream and downstream diversion tunnel portals, the left bank access road and the

trenches in the spillway area, have indicated a sequence of thin, black, carbonaceous marker beds in the Upper Mudrock Sequence, many of which are continuous over large distances. The beds have been successively numbered for reference during the foundation assessment. These beds indicate an upstream dip. Considered three dimensionally, from right to left bank and downstream to upstream on the left bank, and considering several different carbonaceous beds, studies indicate the dip line direction of the bedding varies from $N9^{\circ}E$ to $N32^{\circ}E$, and averages $N17^{\circ}E$. The true dip varies from 0.45° to 0.79° and averages 0.61° . From the downstream spillway area to the upstream diversion tunnel portal area, a particular carbonaceous marker bed therefore decreases in elevation by approximately 8 m. This dip is consistent with the Alberta Syncline measurements previously discussed.

The beds of the Basal Sandstone and Lower Mudrock Sequence are slightly warped, i.e., are not exactly planar from upstream to downstream. The beds in the downstream area near the spillway dip slightly steeper, about 1° , and the beds upstream of the spillway area, slightly less, about 0.3° .

Identification of the major carbonaceous beds in the Upper Mudrock Sequence over much of the site area enabled correlation of individual stratigraphic levels, in spite of the natural vertical and lateral variation of the rock between the carbonaceous layers. This geological understanding then enabled a correlation of the structural features which control the foundation shear strength.

B4.3 ROCK CHARACTERISTICS

Claystone, siltstone and sandstone are the three primary rock types identified on site. Gradational variations such as silty claystone and clayey siltstone are also frequently encountered. The diagnostic features of each of the primary rock types is given in the following (see also Plate B-5).

Claystone

- Grey to dark grey, occasionally black (carbonaceous) or green.
- Calcareous.
- Very silty (silt sizes probably comprise a higher percentage than clay sizes in most rock identified on site as claystone).
- Calcrete nodules locally common.
- Medium plastic clay (CI), occasionally ranging into low and high plastic clay (CL and CH).
- X-ray diffraction analysis of the clay size fraction shows:
 - quartz as the predominant mineral.
 - calcite, dolomite, kaolinite and mica are secondary minerals.
 - smectite and chlorite are present only in trace amounts (smectite is the predominant mineral in bentonite).
- Generally shows a "slow" rate of slaking, although some samples are rated as "very fast".
- Develops a fissured structure as a result of weathering.
- Unconfined compressive strength ranges from less than 1 MPa to 36 MPa, averages 13 MPa.

Siltstones

- Light grey to dark grey, occasionally green or black (carbonaceous).
- Calcareous.
- Ranges from clay- to sand-rich.
- Calcrete nodules locally common.
- Medium plastic clay (CI), commonly ranging from non-plastic, to low plastic silt or clay (ML or CL).
- X-ray diffraction analysis of the clay-size fraction shows:
 - quartz is the predominant mineral.
 - calcite, dolomite, kaolinite and mica are secondary minerals.
 - smectite and chlorite are presented as trace amounts in the majority of samples.
- The significant degree of overlap in plasticity and mineralogy between claystones and finer grained siltstones underscores the difficulty in discerning between the two rocks.
- Occasionally develops a fissured structure as a result of weathering.
- Sandier units often show ripple lamination structures.
- Unconfined compressive strength ranges from 12 to 116 MPa, averages 54 MPa.

Sandstone (Overbank and Shallow Channel Facies Type)

- Light grey to dark grey, some pale brown and pale greenish-grey.
- Generally fine grained (mostly 0.125 mm to 0.25 mm in size), with occasional thin, medium to coarse grained zones.

- Often silt rich.
- Poorly graded (SP).
- Calcrete nodules occasionally present.
- Thin rip-up clast conglomerate composed of mudchips and/or carbonaceous debris occasionally present.
- The clastic components are:
 - quartz (30%), sub-angular to sub-rounded grains.
 - chert (30%), sub-rounded grains.
 - carbonate (30%), sub-angular to angular grains.
 - feldspar, chlorite, white mica, biotite, apatite, tourmaline, opaques, organic matter, zircon and rock fragments (10%).
- The cement components are mainly:
 - carbonate (most abundant).
 - kaolinite.
 - silica.
- Very low porosity (1% to 5%).
- Laminated and bedded structures common.
- Unconfined compressive strength ranges from 12 to 132 MPa, averages 82 MPa.

Sandstone (Deep Channel Facies Type)

- Light grey to grey, some pale brown and pale greenish-grey.
- Fine, medium and coarse grained.
- Poor to well graded (SP) to (SW).
- Beds of rip-up clast conglomerate composed of mudchips and/or carbonaceous debris common.
- Occasional detrital coal pockets.
- Clay balls and claystone or siltstone fragments common.
- The clastic components are:
 - quartz (30%), sub-angular to sub-rounded grains.

- chert (30%), sub-rounded grains
- carbonate (30%), sub-angular to angular grains.
- feldspar, chlorite, white mica, biotite, apatite, tourmaline, opaques, organic matter, zircon and rock fragments (10%).
- The cement components are mainly:
 - carbonate (most abundant).
 - kaolinite.
 - silica.
- Very low porosity.
- Bedded structures common, occasionally laminated structures.
- Unconfined compressive strengths vary from 40 to 100 MPa.

B4.4 JOINTING

B4.4.1 Test Tunnel Mapping

Studies in the test tunnel excavated on the left bank indicated five joint sets as follows:

TABLE B4-2
JOINT ORIENTATIONS IN TEST TUNNEL

SET	DIP (deg.)	DIP DIRECTION (deg.)	REMARKS
1	86	209	Parallel to Set 4
2	85	242	Subset of Set 3
3	84	266	
4	55	205	Sheared, slickensided, with dip slip offsets
5	Subhorizontal		Bedding Joints

Joint Sets 1 to 3 usually characterize the sandstones and stronger siltstones. Joint Set 4 is characteristic of brecciated claystone; these joints often contain clay fillings. Joint Set 5 prevails in all rock types. Most of the joints are tight.

Joint continuity exceeds 4 to 5 m along the strike direction and is about 1 to 2 m in the dip direction. Joint spacing ranges from 0.5 to 2.0 m; locally, closer joint spacing occurs near the seams.

B4.4.2 Drill Hole Studies

Based on studies of the drill holes drilled in the preliminary phase (pre October 1985), the joint spacings were found to be as follows on Table B4-3. Generally joint spacing increases with depth and is highest in the Basal Sandstone.

These joint spacings are considered low estimates of the true in situ joint spacing, considering that most of the drill holes and the major joint sets are subvertical. A more accurate estimate is suggested from the joint spacing in the inclined drill holes V52, D10 and V54; in these holes the joint spacings are usually 1.5 to 3 times greater than the average.

TABLE B4-3
JOINT SPACINGS

ELEVATION (m)	JOINT SPACING (m)			ROCK UNITS
	Left Abutment	Valley Bottom	Right Abutment	
Bedrock Surface	0.14-0.55	-	0.27-0.48	Upper Mudrock Sequence
1070	0.71-1.1	0.59	0.53-2.0	
1040	1.43-10.0	1.43-2.0	1.67-3.33	Basal Sandstone
1010	1.25-3.33	0.77-2.0	-	
				Lower Mudstone Sequence

B4.5 STRUCTURAL FEATURES

Early site investigations indicated that the foundation bedrock was characterized by several types of structural discontinuities or features which were caused primarily by shearing and differential rock movement parallel to the bedding.

In the Preliminary Engineering Report, Appendix D (UMA/Acres (1986)), these features were initially classified as follows:

- Type 1 - shear surfaces
- Type 2 - brecciated zones
- Type 3 - zones of randomly oriented, slickensided surfaces
- Type 4 - friable shear zones

Features of the Types 1, 2 and 3 occur almost exclusively in mudrocks, while Type 4 occurs in sandstone or strong siltstones. Type 1 features are relatively thin seams (usually 1 to 10 mm), which are relatively continuous and conformable with bedding, i.e., subhorizontal. They usually contain fillings of clay/silt and/or rock fragments and occur along geological contacts between relatively strong and weak rocks. Types 2 and 3 are thicker zones which are found throughout an entire bed thickness; fracturing in these features is generally at all orientations and mostly discontinuous. Type 4 features are local and discontinuous.

Types 1, 2 and 3 are often found in association with the black, carbonaceous marker beds. Although Types 1, 2 and 3 features are all generally continuous for considerable horizontal distances, the preferred subhorizontal orientation and the clayey and/or silty fillings of the Type 1 features indicated that these particular features would affect the foundation shear strength most adversely and thus were critical to foundation design. Emphasis was therefore given to the collection of data on the characteristics of the Type 1 features and their assessment for foundation design purposes. To be consistent with the terminology adopted in Section B2.0, the Type 1 features will henceforth be referred to as seams, the term 'shear surface' being used strictly for describing the actual plane of sliding in the stability analysis. Type 2, 3 and 4 features are not discussed in further detail in this report.

The origin of the shear forces which caused the seams is considered to be one or a combination of the following phenomena.

- Glacial ice override.
- Valley rebound during river down cutting. (Matheson and Thomson (1973), Underwood et al (1964)).
- Tectonic forces acting during the formation of the Alberta Syncline.
- Compaction shearing during sedimentation.

No evidence of river bank instability, that can cause seams to develop, was found in the general vicinity of the project site.

Reduction of vertical stress, such as by erosion of overlying bedrock, has probably also contributed to the formation of the seams. Close to the bedrock surface, a higher frequency of seams related to weathering and softening occurs. These seams may not have undergone any shearing.

Although data collected to date do not indicate which mechanism was responsible for which type of feature, it is probable that compaction shearing caused the Type 3 features. Glacial override effects were probably of limited depth and hence tectonic forces and/or valley rebound were likely the predominant causes of the Type 1, 2 and 4 features. Type 1 features in the near surface areas may also be due to weathering and softening effects.

The results of the drilling and the geophysical studies, have enabled the bedrock surface topography in the valley bottom and on the abutments to be determined as is shown in Plate B-6. In the valley, a shallow bowl-shaped bedrock surface exists with a narrow thalweg between Elevations 1044 m and 1045 m. The thalweg is in the middle of the valley in the upstream half of the dam foundation and is in the right half in the downstream half of the foundation. Along the dam axis, the bedrock surface slopes gently beneath the river and more steeply on the right side.

The bedrock surface is at between Elevation 1095 m to 1100 m and 1110 m to 1120 m in the left and right river banks, respectively. The approximate overburden thicknesses in the left and right river banks are therefore 25 m and 10 m respectively. In the valley bottom, the overburden generally varies from very thin at the base of the abutment slopes to a maximum of 15 m beneath the terrace on the right side of the valley. The lowest bedrock surface in the valley bottom is at approximately elevation 1044 m.

The overburden in the river valley, which comprises alluvial sand and gravel and colluvial clay, silt and sand is estimated to be about 9 m deep in the right bank and 3 m to 4 m deep in the left bank.

Plate B-6 also illustrates the limit of areal extent of claystone contained within the Upper Mudrock Sequence between the Basal Sandstone and elevation 1050 m in the river valley bottom. The claystone occurs approximately along the left one-third of the valley bottom and along the

upstream toe of the dam structure. Because the claystone is interbedded within the mudrock sequence, it will not necessarily be exposed when the overburden is removed for construction.

B4.7 BEDROCK STABILITY

The presence of seams and the lower shear strength found along these seams within the bedrock, at the project site has apparently not resulted in any detrimental effects as the site does not exhibit any evidence of rock mass instability. No natural slides exist within the rock mass at the project site, nor within the Porcupine Hills Formation forming the river valley sides upstream and downstream. Shallow overburden slides are found along the sides of the river valley and tributary coulees. These are due to normal erosional processes. Near surface opening of joints and the accumulation of talus and colluvial deposits on the lower slopes are typical.

Surface excavations show a characteristic relaxation of the rock mass surface which is less than the 1% of the dimensions of the material excavated and removed.

Typically, movements decrease with horizontal distance into the slope, and with time. Differential movements coincide with previously identified seams.

Underground excavations of the diversion tunnels did not encounter unexpected instabilities, nor was there any sign of unusual high horizontal stress conditions. Extensometers typically recorded the passage of the excavation front and stabilized about 2 to 3 tunnel diameters behind the face. Typically, total closure measurements were less than 1% of the excavated diameter.

These observations indicate that the design assumptions used are conservative.



B5.0 FIELD INVESTIGATIONS

A number of surface exposures were mapped with a view to obtaining detailed data on the distribution and characteristics of the seams. These mapped areas include:

Left Bank

- Upstream diversion tunnel portal backslope, including the Elevation 1080 bench.
- Downstream diversion tunnel portal backslope.
- Access road at approximate Elevation 1062.

Right Bank

- Spillway area test trenches.

Plate B-7 shows the location of the areas mapped.

B5.1 UPSTREAM DIVERSION TUNNEL PORTAL

Three mapping exercises were performed on the left bank in the upstream tunnel portal area; the first was line mapping along a vertical section parallel to the centre line between the two diversion tunnels, of seams and carbonaceous beds from Elevation 1050 to 1080, using an existing surveyed section. This mapping was done to assess the distribution of the seams and their characteristics in profile from the tunnel elevation up to the Elevation 1080 bench. The seams were located according to stratigraphic position and mapped

as simple seams or compound seams. A simple seam (SSh) was defined as a single seam whose thickness and filling characteristics are as follows:

- a) ≤ 2 mm, filling of clay and/or silt, or
- b) > 2 mm, filling of angular hard fragments of claystone and/or siltstone in a matrix of clay and/or silt.

A compound seam (CSh) was defined as comprising two or more subparallel simple seams in close proximity with the intervening rock being very closely fractured. Thicknesses and orientation of the seams were noted and finally, the ratio of clay/silt matrix to rock fragments was approximated.

The second mapping exercise entailed the description of several, well defined, continuous seams associated with carbonaceous beds which are exposed for a 160-m long length on the Elevation 1080 bench. This face mapping was designed to describe the type, thickness, roughness and continuity of the respective seams. Detailed lithological and structural mapping was done over a height of approximately 4 m at mapping stations spaced every 20 m horizontally along the bench. Numerous 200-mm diameter undisturbed cylindrical core samples were taken at several stations for direct shear testing. Samples of the seam fillings were also taken and tested for the percentage of clay and silt and their Atterberg limits.

The third mapping exercise involved the detailed mapping of wall rock roughness or first order roughness angles along two seams exposed on the Elevation 1080 bench.

The detailed mapping site is located at the western end (downstream) of the Elevation 1080 bench close to chainage 164. The rock face at this location trends approximately N45°E. Two weak seams are exposed here, a relatively thick seam (Seam 3L) comprising a zone of brecciated rock 10 - 150 mm thick of great continuity and a thinner seam (Seam 3U) 5 - 35 mm thick and continuous over a distance of more than 3 m. Both these weak seams are part of Seam 3 referred to in Section B7.3.

A surveyed horizontal reference line was laid out using nails and string at a convenient location between the two seams. This reference line was at elevation 1083.163.

Nails were driven into the seam contacts at all points where there was a change in slope. Each nail was connected by string to define the asperities over the length of the exposure. For the thick seam, the upper and lower contacts were defined in this way since they were not parallel. For the thin seam, only the lower surface was established due to the proximity of the upper surface which was parallel.

By this procedure the asperities having the shortest base lengths were measured. These values are referred to as 'first order' roughness.

Each seam was photographed with respect to the reference line. The following measurements were taken:

- 1) The asperity angle (roughness) defined by the string between any two nails along the surface was measured using an inclinometer. Angles were measured as positive if the apparent dip of the slope was to the west, and negative to the east.

- 2) The slope distance in millimeters along the string between the two nails (base length of asperity).
- 3) The seam was mapped using chainages and offsets from the surveyed reference line and plotted to 2:1 exaggerated scale.

B5.2 DOWNSTREAM DIVERSION TUNNEL PORTAL

At the downstream tunnel portal, mapping was also done along a vertical section between the two tunnel centrelines, from approximately Elevation 1050 to 1080, in order to assess the seams and their characteristics in profile. The type of information collected was identical to that at the upstream portal.

B5.3 ACCESS ROAD

Detailed mapping of a prominent seam exposed along the left bank access road was performed over a horizontal length approaching 500 m. This mapping was designed to obtain data on the type, thickness, roughness and continuity of the seam, as was done for the seams exposed on the Elevation 1080 bench at the upstream portal. Control mapping stations were spaced approximately every 32 m. Some 200-mm diameter cylindrical samples were taken for direct shear tests. Samples of the seam fillings were taken and tested for grain size and Atterberg limits.

B5.4 SPILLWAY AREA TEST TRENCHES

On the right bank, a series of stratigraphically overlapping, 3.0 to 4.0-m high test trenches, S1 to S12, were excavated between Elevation 1072 and 1092 on the natural slope in the flip bucket and chute area of the

spillway. These were mapped along with some existing trenches, R5 to R7, and a 7-m high rock cut at the S716 test anchor installation. Data on the lithology and seams which may correlate with the corresponding data from the mapping of the downstream tunnel portal on the left bank were collected. The same type of information was collected as for the tunnel portal profile mapping. The information collected at the spillway area trenches could also be correlated with data from corresponding stratigraphic levels from the boreholes and shaft S707 drilled in the spillway area.

B5.5 TEST TUNNEL

The test tunnel, excavated on the left bank in the fall of 1985, included a 3.5-m diameter access tunnel (portal crown at Elevation 1062) and 7.5-m diameter test chamber (invert at Elevation 1049 m).

Detailed mapping was performed to obtain data on the distribution and characteristics of the structural features. During the mapping, structural features and structural zones were distinguished on the basis of thickness; structural features were generally single discontinuities, 40 mm or less in thickness; these features were typically subhorizontal, soft, moist to wet clay seams, i.e., Type 1 features. Structural zones were generally greater than 40 mm thick and contained one or more discontinuities. As the structural zones were usually brecciated claystone containing multidirectional fractures and/or slickensided surfaces, some with clay filling, they are not discussed further herein.



A series of drill holes and a shaft (S707) were drilled recently in the spillway headworks and chute area. A series of drill holes and shaft D95 were also drilled in the valley bottom in 1985-86. Shaft D14 was very recently drilled in the valley bottom near drill hole D79. Three, vertically exaggerated, geological sections parallel to the spillway centreline and one section oriented upstream-downstream in the valley bottom, were prepared and designed to emphasize both the weaker clayey strata and the clay/silt-filled seams. Accordingly, only the claystones, silty claystones and clayey siltstones are plotted. Carbonaceous bands are also plotted as well as the slickensided and brecciated zones described in Section B4.5. Various types of core features were identified and were plotted using the following criteria:

TABLE B6-1
STRUCTURAL FEATURES IN DRILL HOLE CORE

FEATURE	CRITERIA
SF1	Zone of fragmented core comprised of rock fragments with clay and/or silt.
SF2	Discontinuity (joint) with immeasurably thin (<1 mm) coating or film of clay and/or silt.
SF3	Discontinuity (seam) with predominantly clayey and/or silty filling; thickness is usually >1 mm.
SF4	Zone of joints with clayey or silty fillings.
CL	Zone of core loss.

In addition to the above, thickness and orientation were plotted for each type of feature.

This method of plotting is slightly modified from that used in the Preliminary Engineering Report and focuses more on the weakest rocks and the clay/silt content of the seams. The reasons for using these criteria are as follows.

The different types of features identifiable in the borehole core were considered to be indicative or suggestive of seams. For example, core features of the SF3 type were considered to be probable in situ seams; furthermore, with a measurable clay/silt filling, they were considered to be among the weakest seams. Similarly, core features of the SF1 type were considered to be equally indicative of seams. SF1-type features are similar to SF3-type features except for 'drill damage'. SF1-type features are usually thicker than SF3-type features and are, by their nature, less definitive regarding the actual position of the seam. SF2-type core features, with their immeasurably thin clay/silt coating or film, are considered to indicate possible seams; shear strength of these very thin surfaces is considered to be higher than those indicated by SF1 or SF3-type features, all other factors being equal.

SF4-type features also may represent possible seams; this designation was used infrequently where definitive depths of a particular clay/silt filled joints were not identified in the logging process.

Zones of core loss, CL, are also used as indicators of possible weak clay/silt-filled seams. CL core features may also be due to drill damage or poor drilling practice. Fortunately, minor core loss occurred.

The distribution of the various core features in a series of drill holes in a given stratigraphic level enabled the identification of the weaker, more continuous and thus critical seams in the rock foundation.

Seams from the shaft were plotted as simple seams (SSh) or compound seams (CSh), as defined in Section B5.1, with their thickness.

5

B7.0 DESCRIPTION OF SEAMS ACCORDING TO LOCATION AND EXPLORATORY
TOOL

B7.1 GENERAL

The objective of the field investigations including the drill hole and shaft data assessment, was to identify and describe the characteristics of the seams existing on site, in terms of the following characteristics.

- position (plan and elevation)
- type
- orientation
- continuity
- thickness
- roughness
- infilling

Some investigative tools used at site enabled a better assessment of the various seam characteristics than others. For example, the most complete description of seams at a particular stratigraphic level was obtained by the mapping of the Elevation 1080 bench of the upstream portal and the access road on the left bank; all the seam characteristics, including continuity and roughness, could be observed and measured. The same applies to a lesser extent in the test tunnel, although the continuity of the seams was limited by the tunnel dimensions.

Mapping along the vertical profile at the upstream and downstream portals and mapping in the shafts provided considerable data on more seams, but relatively little data concerning continuity and roughness.

The drill hole core provided a great deal of data of an inferential nature, i.e., seam characteristics were inferred from core features which had suffered some "drill damage". Since the seams identified by mapping were not drill-damaged, the mapping data are preferred when the overall foundation condition is assessed.

This section will describe the seam characteristics at the various locations and stratigraphic levels and according to the exploratory tool used.

B7.2 ACCESS ROAD, LEFT BANK

The left bank access road is excavated in the lower part of the Upper Mudrock Sequence. A major seam was traced, and mapped in detail every 32 m, for a distance of 350 m along the access road (Plate B-8). It was also exposed at another location 150 m further away, as well as in both upstream and downstream tunnel portals. Continuity of this particular seam is proven for 350 m and is almost certain for 850 m, the distance between portals. It is known to exist also on the right bank.

The seam is conformable with bedding which dips upstream 0.26° from AR-1 to 12, 0.98° from AR-12 to 13B, and 0.53° overall. It is situated at the contact between a 50-cm thick, uniform, dark grey, brecciated claystone and an underlying 10- to 20-cm thick, uniform, black, carbonaceous, brecciated claystone (marker bed 40) containing slickensided surfaces.

The thickness of the seam, i.e., the central most severely deformed area, varies from 10 to 60 mm, averaging 35 mm. The type of seam is a simple seam.

Of the seam infilling material, the estimated ratio of clay/silt matrix to rock fragments is fairly consistent at 60/40.

Roughness measurements on 32-m, 65-m, and 160-m base lengths are as follows:

TABLE B7-1
ROUGHNESS OF ACCESS ROAD SEAM

BASE LENGTH	NO. OF DETERMINATIONS	ROUGHNESS (deg.)	
		RANGE	AVERAGE
32	11	0.03-0.90	0.40
65	5	0.17-0.55	0.35
160 (Ave.)	3	0.11-0.58	0.38

These roughness measurements represent the angular deviations of the actual seam from the average apparent bedding dip surface. The latter is assumed to be the plane along which any future movement would occur.

B7.3 ELEVATION 1080 BENCH, UPSTREAM TUNNEL PORTAL, DETAILED
GEOLOGICAL MAPPING

Three major seams were traced, and mapped in detail every 20 m, for a distance of 160 m along the elevation 1080 bench at the upstream tunnel portal (Plate B-9). The same seams appear at a corresponding stratigraphic position in the spillway on the right bank at approximate Elevation 1089. Minimum proven continuity is, therefore, 160 m and inferred continuity is as great as 900 m.

All three seams are conformable with the bedding. Seam number 1 is at the contact between Unit A, a sandstone, and Unit B, a sequence of alternating, thinly bedded mudrocks. Seam number 2 is within Unit B. Seam number 3 is at the contact of Unit B and an underlying, uniform, grey, sheared claystone; this seam has several associated offshoots. Unit C is underlain by Unit D, a 50-cm thick, black, carbonaceous claystone (marker bed 85) which is sheared and contains discontinuous, slickensided surfaces.

The type and thicknesses of these seams varies substantially. Seam number 1 varies from a simple to compound seam type and the thickness of the individual seams varies from 2 to 10 mm and average 2.5 mm. Seam number 2 is mostly a simple seam type, occasionally a compound seam, with thicknesses ranging from 1 to 40 mm, and averaging 12 mm. Seam number 3 is also mostly a simple seam type, sometimes a compound seam, with thicknesses ranging from 5 to 80 mm and averaging 37 mm.

The infillings for seam numbers 2 and 3 was estimated to be 20-30% clay/silt.

The roughness of the number 1 and 3 seams was assessed and the results are presented below. The roughness of seam number 2 is almost identical to that of number 3.

TABLE B7-2
ROUGHNESS OF ELEVATION 1080 BENCH SEAMS

SEAM	BASE LENGTH (m)	ROUGHNESS (deg.)	
		RANGE	AVERAGE
1	20	0.51-4.59	1.68
	40	0.30-0.47	0.39
3	19	0.18-0.82	0.53

The roughness along seam number 1 is higher than average due to the irregular bedding of the channel sandstone which is immediately above the seam.

These seam roughness measurements compare to the wall rock roughness measurements described in Section B7.4.

Of interest are the offshooting seams (splays) and cross bed seams associated with seam number 3. Most of these associated splays are flat-lying initially and then turn steeply downward and die out in the carbonaceous beds. They have a consistent southerly (SE or SW) apparent dip. Seams 1 and 2 have no associated cross bed shears, probably due to the confining effect of the alternating beds, some of which are relatively strong. Seam 3, however, was apparently not confined by Unit C.

Also of interest is the effect of the channel sandstone deposit between Mapping Stations B19 and B43. The seams apparently pass beneath the sandstone and remain conformable with the bedding.

B7.4 ELEVATION 1080 BENCH, UPSTREAM TUNNEL PORTAL, DETAILED
ROUGHNESS STUDY

Seams 3L and 3U are part of seam 3 described in Section B7.3.

B7.4.1 Seam 3L

Physical Description

The seam is located at an average elevation of about 1082.75 m. Although continuous beyond the area studied,

measurements were only made over a length of about 5.3 m, where the seam was well exposed and the vertical surface was reasonably planar.

The seam varies in thickness from 10 mm to 150 mm (Plate B-10). The upper and lower wall rock surfaces are not parallel and contain asperities with widely ranging base lengths and roughness angles.

The seam itself consists of two parts. An upper zone consisting of multidirectional clay and silt-filled fractures and rock fragments 2 - 5 mm in size with silt to rock percentages varying between 80%:20% to 20%:80% forms the seam over most of its exposed length.

Near the eastern end of the exposed seam, the lower wall rock surface forms a convex downward undulation of about 100 mm below the average adjacent level of the wall rock. The upper zone however parallels the upper contact and "bridges" this lower wall rock asperity.

The material located in the pocket formed by the convex downward undulation of the lower contact is much less brecciated than the upper zone. Thin clay and silt-filled fractures pervade the rock, but the rock fragments are interlocked and form 70-80% of the mass.

This feature indicates that although high angle asperities exist along the upper and lower wall rock surfaces of the seam, the preferred path of shearing was through the filling material at a much flatter angle.

Upper Wall Rock Surface Asperity Measurements

Reference is made to Plates B-12, B-13, and B-14.

- a) A total of 67 measurements of first order asperities were made over a total length of 5.29 m. Values of asperity angle (roughness) ranged between -70° (E) to $+34^{\circ}$ (W) with 80% of the values in the -10° (E) to $+16^{\circ}$ (W) range (Plate B-12).
- b) A total of 67 slope distance measurements were made along the straight line connecting the nails marking the change in slope of the asperities. Values ranged from 20 mm to 319 mm with 80% of the values between 20 mm - 109 mm (Plate B-13).
- c) The absolute value of the asperity angle has been plotted against the measured base length of the asperity in (Plate B-14). The 80% measurement limits have been superimposed for reference. In the 80% limit range for base length measurements, the asperity angle varies between $0-70^{\circ}$ (includes 53 values, 81% of which are lower than 16°). Conversely, the 80% limit range of asperity angle shows a variation in base length between 30 mm and 318 mm (57 values, with 75% in the 20 mm - 110 mm range). Therefore 64% of the total measurements (43 points) have a base length between 20 - 110 mm and a roughness angle of $0-16^{\circ}$. There appears to be a tendency for flatter asperity angle with longer base length.

It is noted that due to the intervals chosen on the histograms for asperity angle and base length, the 80% limits are approximate and that the number of points

included within these limits as shown on the asperity angle versus base length plot may not exactly equal 80% of the total measurements.

Lower Wall Rock Surface Asperity Measurements

Reference is made to Plates B-15, B-16 and B-17.

- a) A total of 58 measurements were made of first order asperities over a total length of 5.35 m. Values of asperity angle ranged between -22° to $+31^{\circ}$ with 80% of the values in the -13° (E) to $+10^{\circ}$ (W) range (Plate B-15).
- b) For the 58 slope distance measurements, the extreme values ranged between 27 mm and 362 mm with 80% of the values in the 50 mm to 150 mm range (Plate B-16).
- c) Within the 80% base length measurements limits, the asperity angles range from 0° - 22° (45 values, 82% of which are less than 12°). Below the 80% asperity angle limit the base lengths vary between 27 mm and 362 mm (49 values, 76% of which are within the "80% of base length measurements limits" of 50 - 150 mm. In other words, 37 points or 63% of the total asperities have base lengths of 50 - 150 mm and asperity angles of 0° - 12° . There is a tendency for the flatter asperity angles with longer base lengths (Plate B-17).

Lower Surface of Upper Zone Asperity Measurements

The roughness measurements along the lower surface of the upper zone where it 'bridges' across the convex downward

undulation were combined with the roughness measurements taken on the rest of the lower wall rock surface beyond the zone of bridging.

Reference is made to Plates B-18, B-19 and B-20.

- a) A total of 62 measurements were made of first order asperities over a total length of 5.35 m. Values of asperity angle ranged between -22° to $+22^{\circ}$ with 80% of the values in the -7° (E) to $+10^{\circ}$ (W) range (Plate B-18).
- b) For the 62 base length measurements, the extreme values ranged between 20 mm to 210 mm with 80% of the values in the 40 to 150 mm range (Plate B-19).
- c) Within the 80% limit of base length values, the asperity angles varied between 0° to 22° (55 points) with 82% less than 10° . Within the 80% of asperity angle measurements, the base length varied between 33 - 210 mm (51 points) with 88% in the 40 mm - 150 mm range. Seventy-two percent of the total number of points have a base length in the range of 40 - 150 mm and asperity angles of less than 10° . There appears to be a general tendency for flatter asperity angle with increased base length (Plate B-20).

Conclusions for Seam 3L

Table B7-3 summarizes the results of the first order asperity measurements taken in seam 3L.

The following observations and conclusions regarding the shear strength of seam 3L can be drawn.

- The preferred path of shearing was through the filling material, despite the high angle asperities of the adjacent wall rock. The upper zone typifies the characteristics of a shear surface. However a single, continuous plane of movement could not be defined.
- The high angle asperities probably served to transfer the shearing stresses more effectively into the filling material.
- During the transfer of stresses, the wall rocks were disturbed to varying degrees before the plane of shearing in the filling material developed.
- As a result, the apparent shear strength of the filling/rock contact will be variable along the length of the discontinuity.
- The seam is not a constant thickness, nor are the upper and lower contacts parallel.
- The base length of first order asperities is within the scale of those sampled by the 200-mm diameter core and tested in the laboratory. Therefore, the laboratory testing will reflect at least the initial shear strength behavior of the seams in the field.
- The maximum range of asperity angles was the largest for the upper wall rock surface (-70° to $+34^{\circ}$) and the least for the lower surface of the upper zone (-22° to $+22^{\circ}$). The lower surface of the upper zone also has the lowest values in asperity angles as confirmed by the 80% value given in Table B7-3, 16° for the upper surface versus 10° for the lower surface of the upper zone. Within the upper zone, multidirectional shear planes occur which, in

turn, are flatter than the wall roughness measured along the lower contact. Therefore the seam roughness on the plane of sliding may approach 0°.

- There is a tendency for longer base lengths to be associated with the flatter asperity angles.

B7.4.2 Seam 3U

Physical Description

This seam is located at an average elevation of about 1083.47. The seam is covered by slope wash debris at the western limit of study and was continuous to the east (upstream). Measurements were taken over a length of 2.5 m. Significant irregularities in the slope to the east prevented taking any more accurate measurements in that direction.

The seam varies in thickness from 5 mm to 34 mm (Plate B-11), and the upper and lower contacts are approximately parallel.

The roughness profile is not highly variable. The seam consists mostly of silt or clayey silt infilling with up to 50% rock fragments.

Since the seam walls were parallel and in close proximity, only the roughness of the lower surface was measured.

Lower Wall Rock Surface Asperity Measurements

Due to the limited exposure length, only 23 asperity angle and base length measurements were made.

Asperity angles ranged between -13° (E) to $+49^{\circ}$ (W) with 80% of the values in the -10° to $+4^{\circ}$ range (Plate B-21).

Base lengths were distributed over a wide range from 20 mm to 295 mm with 80% of the values in the 20 mm to 150 mm range (Plate B-22).

Within the 80% limits for base length, asperity angles vary between 0° to 49° (18 points), 78% of which are less than 10° .

Within the 80% limits of asperity angle measurements, base lengths vary from 47 to 295 mm (19 points) with 74% in the 20 - 150 mm range.

Combining the 80% limits for base length and asperity angle shows that 61% of the total measurements have asperity angles less than 10° and a base length of 20 - 150 mm.

Conclusions for Seam 3U

Due to the limited number of measurements, the conclusions reached may not be as significant as those for the thicker seam (3L). The summary of asperity data for seam 3U is given in Table B7-3.

The range of asperity angles is similar to those obtained for the upper and lower contacts of seam 3L, however the 80% limit values are less widely scattered and are similar to those obtained for the lower surface of the upper zone in seam 3L.

The value of 10° for the 80% limit of asperity angle measurements also agrees with that obtained for the lower surface of the upper zone in seam 3L.

The range of base length values is similar to those obtained in seam 3L both in terms of maximum values and 80% limit. A much flatter distribution in the values was noted; however, this may be due to insufficient readings. There is a tendency for flatter asperity angles with longer base lengths.

This seam is similar to the upper zone found in the thick seam; however, the adjacent wall rocks are not as disturbed.

B7.4.3 General Conclusions

Although this study concentrated on 2 seams at one location, the following points are relevant to the assessment of the shear strength behavior of the seams on a site wide basis.

- 1) Despite the existence of high angle asperities on the wall rock of the seams, shearing occurred through the filling material at much flatter angles. On the actual plane of shearing, asperity angles will approach 0°. Therefore, assigning roughness angles to the seams on the basis of wall rock roughness measurements alone will over estimate the in situ shear strength.
- 2) The base length of first order asperities measured in the field is of the same order as those found in the 200-mm diameter cores tested in the laboratory. Therefore, the shear strength behavior of the material in the laboratory, at least in the early stages, will include the effect of high angle asperities and will model the behavior of the seam in the field.

- 3) For the roughness angles measured, 80% of the first order asperity angles were less than 16° . This implies that second, third and higher order asperities over longer base lengths will have even lower values. This was substantiated by the other investigations which found an average angle of 0.5° over 20 - 160 m long base lengths. For the lower surface of the upper zone in seam 3L, 20% of the roughness measurements are less than 10° . Therefore, as the level of shearing increases, the maximum roughness angles on the wall rock also decreases.
- 4) The apparent shear strength of the wall rock of the weak seams will vary due to disturbance during shear. The actual wall rock shear strength will depend on residual rock to rock strength and the residual filling material strength.
- 5) Seams are not of constant thickness nor are their sides parallel. Their complex variability in terms of geometry, filling material and thickness makes it difficult to predict the true effect of any roughness components on the basis of theoretical principles alone. Assuming that the filling material is incompressible during shear; failure may take place in the following ways:
 - a) Failure through the filling material on either pre-sheared planes or new planes.
 - b) Failure along the filling/rock wall contact.
 - c) Failure through the asperities along the rock walls.

TABLE B7-3

ROUGHNESS DATA - SEAMS 3L AND 3U, ELEVATION 1080 BENCH

SURFACE	MAXIMUM RANGE VALUES		80% LIMIT VALUES		COMBINED 80% VALUES	
	ASPERITY ANGLE*	BASE LENGTH	ASPERITY ANGLE	BASE LENGTH	ASPERITY ANGLE	% OF TOTAL
Upper Wall Rock	-70° to +34°	24-318 mm	-10° to +16°	20-109 mm	16°	64%
Lower Wall Rock	-22° to +31°	27-362 mm	-13° to +10°	50-150 mm	12°	63% Seam 3L
Lower Contact of Upper Zone	-22° to +22°	20-210 mm	-7° to +10°	40-150 mm	10°	72%
Lower Wall Rock	-13° to +49°	20-295 mm	-10° to +4°	20-150 mm	10°	61% Seam 3U

* + Angles are dipping to the West
 - Angles are dipping to the East

Each of these modes of failure may take place along a given seam under the same shearing stresses due to the variability of the seam properties.

Laboratory shear box test results done on samples of the same seam from various locations will therefore provide an acceptable range of values which reflect the variability of the physical properties of the seam in the field.

B7.5 TEST TUNNEL

The test tunnel was constructed in the lower part of the Upper Mudrock Sequence. The tunnel passed through a 13-m high stratigraphic section, comprising 10 m of alternating claystone and siltstone overlying 4 m of channel sandstone. Numerous structural features, i.e., seams, were identified in the test tunnel mapping; at least 11 of the seams identified in Table B7-5 are clay-filled seams which are conformable with the bedding. Most of the seams are at the upper or lower contacts of claystone beds.

The thicknesses of these seams range from less than 1 mm to 80 mm and average 6.5 mm.

The continuity of the seams was measured. This ranged from 8 to 40 m and averaged 24 m; these continuities were limited by the tunnel dimensions hence, the true continuity is greater.

Roughness of various seams was assessed. Table B7-4 presents the results.

TABLE B7-4
ROUGHNESS IN TEST TUNNEL

SEAM NO.	BASE LENGTH (m)	ROUGHNESS (deg.)	
		RANGE	AVERAGE
5	10	1.46-1.63	1.54
12	10	0.83-1.57	1.13
15	10	0.60-1.34	0.90

Roughnesses calculated from some of the measurements in Table B7-5 over extremely short base lengths of less than one metre approach 40 to 60.

B7.6 UPSTREAM TUNNEL PORTAL VERTICAL PROFILE

Mapping in the Upper Mudrock Sequence at the upstream portal (Plate B-24) indicated, in addition to the seams on the Elevation 1080 bench above carbonaceous bed 85, numerous simple seams between elevation 1070 and 1080, associated with carbonaceous marker beds 60 to 75, also simple seams at Elevation 1065 and Elevation 1061 (at carbonaceous bed 40), a compound seam just below Elevation 1060 and several simple seams in the tunnel elevation. The seams are conformable with the bedding and generally occur at the bedding contacts.

The lateral continuity of the seams was not assessed because of the talus covering the slope.

The thickest seams are at the Elevation 1080 bench and elevation 1061, where the seams range from 20 to 50 mm; these are the same seams discussed in Sections B7.2 and B7.3, respectively. The other seams are much thinner,

TABLE B7-5
TEST TUNNEL MAPPING
SUMMARY OF STRUCTURAL FEATURES

SEAM	THICKNESS (mm)			AMPLITUDE			WAVINESS (mm)			WAVELENGTH			GENERAL DESCRIPTION: Type, Orientation, Persistence (P), Consistency, Waviness, Wetness, Appearance
	MIN.	MED.	MAX.	MIN.	MED.	MAX.	MIN.	MED.	MAX.	MIN.	MED.	MAX.	
1	-	22	-	-	30	-	-	-	190	-	-	-	Clay seam, planar, 02°/210°, P>8 m, soft, moist, wavy, possibly correlates with seam 18.
* 2	-	4	-	-	45	-	-	-	500	-	-	-	Clay seam, dip 18° toward left wall (perpendicular to tunnel axis), P=1 m, wavy. Splays between seam 1 and seam 3.
* 3	-	14	-	-	20	-	-	-	650	-	-	-	Clay seam, 20°/268°, P>6 m, wavy, splays into seam 2 (5 mm thick); locally bottom contact of clayey siltstone (Unit 8). Possibly correlates with seam 17.
* 4	-	-	-	-	-	-	-	-	-	-	-	-	Two thin, intact silty claystone bands, P=1 m, moderately weak.
5	1	2	30	10	-	11	200	-	300	-	-	-	Clay seam, forms top of claystone (Unit 4), P>40 m, soft, wavy, moist, some splays.
** 6	1	25	260	-	-	-	-	-	-	-	-	-	Clay seam, occurs within structural zone SZ-1, P=10 m, thickness varies greatly.
** 7	3	7	20	-	4	-	-	-	600	-	-	-	Clay seam, locally silty.
* 8	-	-	-	-	-	-	-	-	-	-	-	-	Forms lower contact of channel sandstone, slump structures (?), claystone blocks containing "rip-up" clasts, brecciated, slickensided.
9	-	-	-	-	-	-	-	-	-	-	-	-	See seam 15 for description.
10	-	20	-	-	-	-	-	-	-	-	-	-	Clayey seam, soft, wet, lower contact of claystone (Unit 4).
11	2	5	15	-	-	-	-	-	-	-	-	-	Clay seam, P=18 m, soft, lower contact of SZ-5 and sandy siltstone (Unit 3).
12	1	3	20	10	18	40	150	350	600	-	-	-	Clay seam, P=26 m, soft, upper contact of claystone (Unit 4).
13	0.5	2	6	12	20	30	350	600	800	-	-	-	Clay seam, P=36 m.
** 14	1	3	5	-	-	-	-	-	-	-	-	-	Clay seam, P=2 m.
15	0.5	3	80	15	18	50	150	750	1200	-	-	-	Clay seam, P=16 m, may be continuous with seam 9. Upper contact of clayey siltstone (Unit 6).
16	2	9	23	-	10	-	-	300	-	-	-	-	Clay seam, P=18 m.
17	0.5	2	50	8	-	15	180	-	650	-	-	-	Clay seam, P=32 m, soft, wavy, usually at the top of a carbonaceous zone.
18	1	2	19	15	20	10	650	800	1000	-	-	-	Clay seam, P=20 m, wavy.
19	-	3	-	-	15	-	-	600	-	-	-	-	Clay seam, P=2 m, at top of a minor carbonaceous zone.

*Discontinuous, not parallel to bedding, or anomalous features.

**Orientation not specified.

ranging from 1 to 10 mm and averaging 4 mm. Infillings of the seams less than 2 mm thick are 100% clay or silt; thicker seams show complete variation in the ratio of fines matrix to rock fragments.

Plate B-24 shows the very thick channel sandstone deposit forming the slope above the Elevation 1080 bench.

B7.7 DOWNSTREAM TUNNEL PORTAL VERTICAL PROFILE

Mapping in the Upper Mudrock Sequence at the downstream tunnel portal (Plate B-25) indicated several simple seams above Elevation 1075, associated with carbonaceous beds 55 to 65, another simple seam at Elevation 1069 (carbonaceous bed 40) another at Elevation 1065 and several including a compound seam, in the channel sandstone below Elevation 1062. These seams are conformable with bedding and occur generally at, or near bedding contacts.

As at the upstream portal, talus material precluded measurement of lateral continuity of the seams.

The thickest seams are those at Elevation 1082.5, up to 110 mm, Elevation 1068.5 (associated with carbonaceous bed 40), 60 mm, Elevation 1059, up to 50 mm; the remaining seams are generally 5 mm thick or less. Infillings of those seams less than 2 mm thick are 100% clay/silt matrix, whereas those thicker than 2 mm show wide variation in the ratio of clay/silt matrix to fragments.

As with the upstream portal, a large channel sandstone deposit exists above Elevation 1083.

B7.8 SPILLWAY AREA TRENCHES

Plate B-26 shows the results of the trench mapping in the spillway flip bucket and chute area. The rock in this area is all part of the Upper Mudrock Sequence.

Fourteen seams were identified between Elevation 1070 and 1095; they are more frequent between carbonaceous beds 65 and 75 (Elevation 1083 - 1086.5) and 80 and 85 (Elevation 1087 - 1090). Simple seams also occur at Elevation 1095, Elevation 1076.8, Elevation 1075.4 (at carbonaceous bed 50) and at Elevation 1069.6 (at carbonaceous bed 40).

The majority are simple seams, although many compound seams occur. Some seams change from one type to another. Most are conformable with bedding; a few are inclined. Many of the seams are associated with particular carbonaceous beds or slickensided beds of claystone.

Many of the seams have been identified in corresponding stratigraphic positions in adjacent trenches. This allows an estimate of continuity; several are continuous for approximately 25 m.

The seams vary substantially in thickness. Simple seams vary from 1 to 100 mm in thickness. Compound seams vary from 3 to 100 mm in total thickness and show as many as 15 individual very thin (<1 mm) seams. Weathering may have caused some of these seams to appear thicker than they are in situ.

The thinner seams contain predominantly clay/silt infillings, while the thicker ones show infillings which are predominantly rock fragments.

B7.9 SPILLWAY AREA SHAFT

The shaft S707 which extended through the Upper Mudrock Sequence to approximate Elevation 1080 encountered predominantly simple seams and a few compound type seams (Plate B-28). The majority of the seams occur in the upper 14 m of bedrock, i.e., above Elevation 1104. In this upper section there are 22 simple type seams and 3 compound type seams, resulting in an average spacing of 0.6 m between seams. Below this depth, there are only 6 seams for an average spacing of 3.8 m. This concentration of seams in the upper bedrock appears to relate to weathering. A zone of weathering has been defined accordingly.

The seams are up to 50 mm in thickness; most however, are less than 20 mm. They are all conformable with bedding; some are within rock units and some are at contacts. Most occur in claystone and many are associated with carbonaceous and/or slickensided beds.

As will be discussed in Section B7.10, the seams in the shaft and those in the neighbouring drill holes have been combined in the overall seam assessment for the spillway area.

B7.10 SPILLWAY AREA DRILL HOLES

Most of the drilling in the spillway area was confined to the Upper Mudrock Sequence.

Plates B-27, 28 and 29 represent three geological sections which are parallel to the spillway centreline and subparallel to the strike of the bedding. The diagnostic indicators of seams, viz., SF1, SF2, SF3, SF4 and CL, as well as the relatively weak, clayey rock types and the

carbonaceous, slickensided and brecciated beds are shown on the sections. The numbered carbonaceous marker beds identify the stratigraphic levels.

SF1, SF2 and SF3-type features comprise the majority of diagnostic features plotted, with SF2s being the most numerous.

As with the shaft S707, the frequency of features is relatively great in the upper 10 to 15 m of bedrock; a zone of weathered rock has thus been indicated.

Features found at depth are often found in clusters spanning 0.5 to 1.0 m. The majority of the features are in claystone, silty claystone or clayey siltstone.

To infer the seams on a particular section, the distribution of the core features in the various stratigraphic levels was studied from drill hole to drill hole and drill holes to shaft. Stratigraphic levels characterized by more than an average number, or cluster, of diagnostic features were identified. Those containing one or more SF1s or SF3s were identified as potential seams. Up to seventeen such seams, depending on the section, were identified, as shown on the plates. It is noted that corresponding seams appear on adjacent sections, but at different elevations; this is explained by the 1° dip which exists in the spillway area. Depending on their continuity which is discussed in a later section, some seams exist on only one or two of the three sections.

Due to the higher seam frequency in the upper bedrock, seams were identified in a given stratigraphic level based on their definition in the unweathered rock, i.e., the more

western holes. Where the bedrock in all drill holes was weathered, it was not possible to distinguish particular seams.

Studies of roughness of the various postulated seams were performed, both along the strike line which is subparallel to the spillway centreline, and along the dip line. Roughness measured along the strike line is, in 90% of the cases, less than 0.4°. Roughness along the dip line in 95% of the cases is less than 0.6°.

B7.11 VALLEY BOTTOM SHAFT

Shaft D95 was collared at Elevation 1070 in the Upper Mudrock Sequence and extended down to Elevation 1022 in the middle section of the Basal Sandstone.

Below Elevation 1060, this shaft encountered 10 simple seams and 2 compound seams (Plate B-30); seven of the seams occurred in the Upper Mudrock Sequence, none in the upper section of the Basal Sandstone and five in the middle section of the Basal Sandstone. Most occur in claystone and along geological contacts. The thickness of the seams often varied across the diameter of the shaft by as much as 10 or 20 mm. The thickest seams measured 60 mm; about half of the seams were 30 mm or less. One of the compound seams has a total thickness of 300 mm.

The results of shaft D14 are not plotted.

B7.12 VALLEY BOTTOM DRILL HOLES

The valley bottom drill holes are usually collared in the Basal Sandstone, except in the upstream area, where they are collared in the overlying Upper Mudrock Sequence; most of

the drill holes pass through the Basal Sandstone and many penetrate a considerable depth into the Lower Mudrock Sequence.

Plate B-30 is a geological section trending upstream - downstream, i.e., subparallel to the dip line of the bedding. The upper 10 m of the shaft D95 is not plotted. Carbonaceous beds, although plotted, are not identified as marker beds in the Basal Sandstone, since the stratigraphy is fairly well defined.

The diagnostic indicators of the seams, as well as the weaker rock units, are shown on the section, as was done for the spillway drill holes.

Of all the diagnostic indicators, the SF1s and SF3s predominate, unlike for the spillway area, where SF2s were more frequent. In the valley bottom, however, core losses were more frequent. As with the spillway drill holes, the core features often occur in clusters.

Using the same criteria explained in Section B7.10, twenty-one seams were identified above Elevation 980.

A study of roughness of the various seams along the dip line has indicated that 90% of the values were less than 0.4°.

Continuity of the seams varied from about 100 to 700 m.

Plate B-31 shows the correlation of the carbonaceous marker beds in the Upper Mudrock Sequence from the upstream to downstream portal on the left bank and across the river to the spillway area on the right bank. The carbonaceous beds are numbered in ascending order from the valley bottom. The left bank section is subparallel to the dip line of the beds and is based on a study of drill hole data and portal mapping data. The right bank section is subparallel to the strike of the beds and is based on data from the trenches, the shaft and numerous drill holes. The latter are represented by a single typical drill hole; data from drill holes off the spillway chute centreline have been projected up-dip or down-dip, as required.

In general, the correlation of carbonaceous beds across the site is very good. It is noted that the carbonaceous beds above bed number 70 are not represented in the upper part of the rock exposed in the downstream portal; this is due to the channel sandstone which effectively replaced the pre-existing mudrock material. The variability of the rock from one place to another between the same carbonaceous beds is apparent.

The seams which were observed and inferred in the various areas are plotted. The purpose of the stratigraphic correlation exercise was to assist in determining the continuity of the seams, i.e., if the seams plotted in corresponding stratigraphic positions from one place to another on site, this would suggest continuity of the seams.

Considering the seams in the left bank from the upstream to downstream tunnel portal, below the channel sandstone stratigraphic level, some seams, namely, those associated with carbonaceous beds 40 and 70, correlate well. Others do not. Continuity is thus variable.

Considering the section from the upstream portal to the spillway trenches, there is a good correlation of seams between carbonaceous beds 60 and 75. This is not the case between the upstream and downstream portals which is explained by the channel sandstone. There is also good correlation of seams at or close to bed 85 and bed 40.

Considering the section from the spillway trenches to the drill holes, there is good correlation of seams associated with carbonaceous beds 80, 85 and 95; below this, they correlate poorly, except at beds 65, 50 and 40.

Considering the section from the drill holes to the shaft, the correlation of seams varies from poor to good.

The above results indicate that the continuity of the seams varies substantially; some, such as those associated with carbonaceous beds 80 to 85 and bed 40, appear to have much greater continuity than others. The continuity of other seams must be evaluated specific to the area of interest.

B9.0 GENERAL SUMMARY OF SEAM CHARACTERISTICS

The data characterizing the properties of the seams as collected at the various elevations and site locations, can be synthesized and summarized as follows.

B9.1 SEAM CONDITION AND SHEARING MECHANISM

The fragmented and softened state of the infillings in the seams and the association of many of the seams with other types of rock deformation strongly suggests relative movement.

In thick seams, a well defined shear surface is often not found. Instead, individual very thin clay/silt-filled seams exist which increase in frequency in the zone of greatest deformation. The relative displacement of the rock on either side of the seam may be the result of the sum of smaller movements occurring on many sub-parallel individual shear surfaces within the seam. This implies that the shear forces from the adjacent rock are transferred into the weaker material progressively. During shearing, individual shear planes of limited extent develop wherever the shear strength of the material is exceeded. Once shearing occurs, the shear stresses are shed to adjacent material which may fail along another shear plane or by extension of the previous plane, depending on the local wall rock geometry (roughness, thickness).

The individual shear planes may have reached residual values; however, the whole seam or even a given plane within the seam may not have reached the residual value. In thinner seams, there is more evidence to define possible single surface along which most of the relative displacement has occurred.

Softening due to weathering effects may also create seams that have not undergone shearing. These may resemble simple seams visually, but they are not at a residual strength condition.

B9.2 POSITION, ASSOCIATION AND FREQUENCY

The seams occur in numerous areas throughout the site and at various positions throughout the stratigraphic profile. The seams are often associated with the sequence of black carbonaceous marker beds; this association enables the study of a particular seam at various locations on site. The seams are also often associated with other types of rock deformation, such as zones of brecciated rock and/or zones of slickensided surfaces. The seams are usually found in the weaker mudrocks, i.e., those with relatively high clay content. They occur along geological contacts between relatively weak and strong rocks. As a consequence, the seams are more frequent in the Upper Mudrock Sequence, moderate to least frequent or non-existent in the Basal Sandstone, depending on the mudrock content and are moderately frequent in the Lower Mudrock Sequence.

B9.3 TYPE

The predominant seams, as observed in mapping, exist as a single seam; occasionally, several single seams exist within centimetres of each other, forming a compound seam. In the latter, the rock between the adjacent seams is usually closely fractured. Single-type seams can change to compound type seams in a horizontal distance of 10 m.

B9.4 ORIENTATION

The orientation of the vast majority of the seams is parallel to the bedding. Occasionally, as was seen on the Elevation 1080 bench, offshoot seams or splays are initially oriented subparallel to the main seam and then diverge sharply and disappear. These splays can result in a deceptive apparent orientation of seams.

B9.5 CONTINUITY

The continuity of the seams appears to vary substantially. Some seams such as those associated with the carbonaceous marker beds 40 and 80 to 85 are very continuous, i.e., up to 1000 m. Other seams above the river level have continuities ranging from less than 50 m to more than 400 m. Drill holes in the river bottom suggest at least one seam at the bottom of the Basal Sandstone extends for 700 m, and several others, 200 to 300 m.

B9.6 WALL ROCK ROUGHNESS

There is a general tendency of decreasing roughness angle with increasing base length. Wall rock surfaces can also have a varying range of roughness angles depending on the amount of relative movement that has occurred. For higher order asperities over longer base lengths, the average roughness values will decrease due to geometric effects.

Based on the measurements over various base lengths, the wall rock roughness varies from a maximum of 10° to 16° for first order base lengths in the 100 mm range to about 4 to 5° in the 1-m base length range. Beyond this length, the wall rock roughness approaches the values measured for seam roughness from surface exposures.

B9.7 SEAM ROUGHNESS

The most reliable estimates are derived from surface exposures where seams can be traced over tens to hundreds of metres. Measurement of the seam roughness of structural features in the test tunnel at 10-m base lengths ranged from 1.0 to 1.3°. Over base lengths of 20 to 60 m for seams in claystone, roughness averaged 0.5°. The majority of measured roughness values in claystone vary from 0° to 0.9°.

B9.8 THICKNESS

The thickness of the seams varies from fractions of a millimetre, as demonstrated by the SF2-type features in the drill holes, to as much as 60 or 70 mm, as demonstrated by many of the SF3 and SSh-type features. Thicknesses can change by as much as 50 to 90% in a horizontal distance of 10 m.

B9.9 INFILLING

The infilling of those seams which are less than 2 mm thick, contain relatively uniform fillings of clayey silt or silty clay. Those which are thicker usually contain a mixture of clay/silt matrix and angular claystone fragments; the ratio of matrix to fragments is highly variable from one location to another within a given seam.

B9.10 WEATHERING

There is an increased frequency of seams in the upper 10 to 15 m of bedrock. This appears to be related to the softening effects of weathering. As discussed, these seams may not have undergone relative movement and therefore may have greater relative shear strength.

The characteristic variability of the seams is a reflection of their origin. In Section B4.5, the various geological phenomena which give rise to shear forces were briefly discussed. These forces were active at various periods in the geologic history of the bedrock and consequently result in different engineering implications on foundation shear strength.

During deposition and before lithification of the sands, silts and clays; density and water content variation led to differential compaction and local slumping of the beds. Scouring of river channels within the previously deposited sediments caused localized slides and displacements of beds to occur.

These features are preserved in the rock as lithified features such as minor offsets in bedding laminations within a bed, rotated beds along the sides of channel sandstones and conformable undulation of the beds due to the weight of overlying strata.

Within the mudrocks, multidirectional slickensides may be due to differential compaction of a bed of clay-rich material. These types of features are not directly the result of shearing forces. In their lithified undisturbed state, peak values of shear strength still exist.

Thin, interbedded clay/silt-rich units are sometimes found which represent the end of one deposition cycle. These seams may or may not become sheared later, resulting in a variation of in situ shear strength values.

Tectonic forces acting during the formation of the Alberta Syncline may result in interbed shearing. Since the beds are only mildly warped at the dam site, the relative movement would have been confined to the existing bedding planes, particularly those between relatively strong and weak rocks. Depending on the degree of interbed shearing, secondary shear features may result. These include splayed seams which originate along the bedding plane and diverge into the weaker rock, pockets of brecciated rock where stresses were concentrated at a bedding undulation, secondary shearing within the weaker rocks such as the claystone due to stress transfer from the adjacent rock units. These types of features will have shear strengths below peak values and may approach the residual in some cases. Depending on the stress history, some seams may not have sustained shearing forces for the same length of time. Subsequent diagenetic processes may tend to re-establish the shear strength of a given seam.

Valley rebound during river downcutting is a complicated phenomena. Removal of the rock mass in the river valley generally allows inward relaxation of the abutments and upward movement of the valley floor.

Removal of the overlying sedimentary rock sequence over geologic time has also resulted in a general relaxation of the rock mass and reduction of vertical load.

The shear forces related to valley rebound may develop as a result of the differential horizontal moduli (or stiffness) of each rock layer. Rocks of high modulus such as sandstone and cemented siltstone would not relax to the same amount as those of lower modulus, such as claystone and weak

siltstones. As a result, interbed shearing would develop new seams and remobilize movement on any existing seams. These seams may be sheared to close to their residual condition.

The Basal Sandstone acts are a stiff member in the valley floor tending to resist upward deflection and shearing within itself. However, the adjacent mudrocks will contain numerous seams related to shearing imposed by the inward movement of the abutments. These seams will continue into the abutments to a point where the shearing forces are diminished. Within the Basal Sandstone, the imposed shearing forces and tendency for upward deflection results in the opening of bedding planes. Mudrock units within the Basal Sandstone such as Structural Units Number 1 and 2 will develop seams as a result of these imposed stresses.

Along the valley sides, signs of stress relief are evident. The channel sandstone units are jointed subvertically subparallel to the the valley wall and the joints are open for several centimetres.

Glacial ice override effects are expected to occur in the near bedrock surface area and diminish with depth. The imposed weight of glacial ice and shearing forces may have occurred contemporaneously with valley down cutting.

Due to the horizontal nature of the beds, shearing effects due to the overriding of continental glaciation would affect the upper layers first. Disruption of the strata and opening of vertical joints followed by infilling with glacial till debris, where noted, occurred only in the upper few metres of the bedrock surface.

Weathering affects each of the rock units differently. Development of softened rock along bedding planes due to varying clay content and degree of cementation results in seams which may not be related to any shearing forces. As the rock relaxes, the amount of softening spreads laterally along a given bedding plane. Alternatively, pre-sheared seams may be preferential paths of weathering. Percolating groundwater depositing iron oxide and carbonate minerals may result in some degree of recementing. These types of seams are expected to increase in frequency close to the bedrock surface and have limited continuity.

In summary, the valley rebound and regional tectonic effects are the most significant effects on foundation shear strength. While it is not possible to determine the origin of a particular seam, it is important to realize the seams originated from various phenomena, each implying different levels of shear strength available and lateral continuity.

B10.0 IDENTIFICATION OF CONTINUOUS SEAMS

Seams have been identified - either as observed by mapping at the surface or in shafts, or inferred from drill hole core - at various locations and at various stratigraphic levels in the spillway and dam foundations. For design purposes, the critical seams which will control the foundation shear strength and ultimately the stability of the structures, must be selected from all the seams identified. The primary criteria for the selection of these critical design seams is their continuity, i.e., seams observed or inferred to exist over a wide area relative to the structure under consideration will adversely affect the foundation shear strength, whereas local seams will not significantly affect the overall shear strength. The continuity of the various seams does vary and hence, it must be inferred in the area of interest using data from drill holes, shafts and trenches.

In a given drill hole, a seam is inferred to exist where the SF1, SF2, SF3, SF4 and CL-type core features are relatively frequent, i.e., where these core features are clustered. Such clusters can commonly exist over a vertical drill hole length of up to 0.5 m, reflecting subsidiary seams relating to the principle seam.

Continuity of a given seam can be inferred between drill holes, assuming the seams are parallel to the bedding. If a given seam is observed to exist in numerous drill holes distributed over a particular structure foundation area, then the seam can be described as being continuous over that foundation area. If exposures of the same seam exist in a shaft or in excavated trenches in the same area, these are further indications of the continuity of the seam.

Accordingly an assessment of the continuity of seams was performed for both the spillway and the dam foundation (valley bottom) areas. In the latter case, the assessment was done for both the upstream and downstream shell areas. The assessment is mainly based on the relative percentage occurrence of the various types of features diagnostic of the seams, i.e., SF1, SF2, SF3, SF4, SSh and CSh features. Thus the first criterion for continuity is that the relative occurrence of a given seam among drill holes, shaft S707 and trenches, if applicable, exceeds 40%. A second criterion which was applied in the spillway, where three lines of boreholes exist, is that the occurrences be distributed in all three lines of boreholes.

Tables B10-1 and B10-2 present the results of the continuity assessment for the spillway area which is based primarily on the data from the drill holes and the trenches and supplemented by data from the shaft above Elevation 1080. Seams are identified according to a reference elevation on the spillway centreline which is subparallel to the strike of the beds, i.e., the elevation is constant. They are also identified relative to the carbonaceous marker beds. Using the criteria given above, a total of 11 continuous seams and 6 discontinuous seams were identified.

Tables B10-3, B10-4 and B10-5 present the results of the continuity assessment for the upstream and downstream shell areas which is based primarily on data from drill holes and supplemented by data from the shaft D95 above Elevation 1020. Seams are identified according to a reference elevation on the dam axis. Seams are also referenced to the main stratigraphic contacts, rather than carbonaceous beds.

TABLE B10-1
ASSESSMENT OF SEAMS IN SPILLWAY AREA

SEAM NO.	REFERENCE ELEV. AT SPILLWAY CENTRELINE	POSITION RELATIVE TO CARBONACEOUS BEDS	(1,2) STRUCTURAL FEATURES/THICKNESS (mm)						(3) RELATIVE OCCURRENCE (%)	FEATURES APPEAR IN ALL THREE DRILL HOLE SECTIONS	
			SF1	SF2	SF3	SF4	CL	SHAFT SSH		TRENCHES CSH	YES
R1	1068.2	At bed #40	1/510 1/300 1/30 1/40 1/90 1/160	13	1/10 2/20 1/40 1/60	1	1	1/65	73	X	
R2	1074.0	Just below bed #50	1/210	3	3/10	1			40		X
R3	1078.5	At or just above bed #50	1/30		3/3	1	2		36	X	
R4	1081.5	Just below bed #65		2	1/30 1/5				13		X
R5	1083.0	Midway between beds #65/70	1/30	9		1			33		X
R6	1084.5	Midway between beds #70/75	1/20 1/260	9	1/2 1/5 1/-			1/20 1/5	67	X	
R7	1086.5	Midway between beds #75/80	1/90	5	1/2	1			53	X	
R8	1087.5	Just below bed #80	1/100	13	1/- 1/30 2/10-30 1/80 1/3 1/20		1	1/50 1/10	53	X	
R9	1088.5	Midway between beds #80/85 or at bed #80	1/-	11	2/20 2/30 2/2 1/5	2	2	1/50 1/100	93	X	
R10	1089.5	At or just below bed #85	1/120 1/90	4	2/10	1			53	X	
R11	1090.5	Just above bed #85	1/20 1/270	2	1/40	1	1	2/10	40	X	
R12	1095.5	Just below bed #95	1/350 1/20	5	1/30			1/2	40	X	
R13	1096.5	Just below bed #95	1/140 1/350	5	1/50 1/90	1		1/10	53	X	

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TABLE B10-1 (Cont'd)
ASSESSMENT OF SEAMS IN SPILLWAY AREA

SEAM NO.	REFERENCE ELEV. AT SPILLWAY CENTRELINE	POSITION RELATIVE TO CARBONACEOUS BEDS	(1,2) STRUCTURAL FEATURES/THICKNESS (mm)										(3) RELATIVE OCCURRENCE (%)	FEATURES APPEAR IN ALL THREE DRILL HOLE SECTIONS YES NO
			DRILL HOLES			SHAFT & TRENCHES				SSH	CSH			
			SF1	SF2	SF3	SF4	CL							
R14	1099.8	Below bed #100	1/50 1/30 1/20 1/130 1/230 1/40	8	1/- 1/10 1/20		1	1/2-10			64	X		
R15	1102.0	Below bed #105	1/420 1/170 1/150 1/30	1	1/140		2	1/10			54	X		
R16	1105.0	At bed #110	1/250 1/40	9	1/60 1/40 2/30		2	1/20 1/10-40			81	X		
R17	1107.7	Just below bed #115	1/360 1/170	5	1/50 1/5-7 1/10 1/70 1/2		1	1 2/15			100	X		

NOTES:

- (1) Number of occurrences in drill holes, shaft and trenches within 0.5 m of reference elevation, adjusting for dip.
- (2) Thickness not given for SF2, SF4, CL features.
- (3) Number of actual occurrences/number of possible occurrences.

In the upstream shell area, a total of 11 continuous and 10 discontinuous seams are identified. In the downstream shell area, a total of 5 continuous and 16 discontinuous seams are identified.

Continuity using the above criteria is inferred to be structure-wide; in some instances in the spillway area, some seams identified as continuous above may be shown to be absent over relatively short lengths at certain elevations. These seams may thus be deleted for design considerations. Similarly, some continuous seams in the valley bottom may not exist due to the erosion by the river in the downstream shell area; they would, however, exist in the abutments in the downstream area. These seams can also be deleted for design purposes. This aspect is discussed in further detail in Section B13.0.

TABLE B10-2
CONTINUITY OF SEAMS IN SPILLWAY AREA

SEAM	CONTINUOUS	DISCONTINUOUS
R1	X	
R2		X
R3		X
R4		X
R5		X
R6	X	
R7	X	
R8	X	
R9	X	
R10	X	
R11		X
R12		X
R13	X	
R14	X	
R15	X	
R16	X	
R17	X	

TABLE B10-3
ASSESSMENT OF SEAMS IN VALLEY BOTTOM

SEAM NO.	APPROXIMATE POSITION RELATIVE TO MAJOR GEOLOGIC CONTACTS (1)	REFERENCE ELEVATION AT DAM AXIS (m)	(2,3) STRUCTURAL FEATURES/THICKNESS (mm)					(4) RELATIVE OCCURRENCE IN SHELL OF DAM (%)	
			DRILL HOLES					UPSTREAM	DOWNSTREAM
			SF1	SF2	SF3	SF4	CL		
V1	LMS: 19.5 m below BS	986.6	1/10 1/30	2			(5)N/A	33	33
V2	LMS: 17.5 m below BS	988.5	1/60 1/170	5	1/20		N/A	50	33
V3	LMS: 15 m below BS	990.8	1/10 1/20 1/40 1/100 1/-	1		1	N/A	50	33
V4	LMS: 13 m below BS	993.2	3/40-70 1/100 1/130				N/A	0	67
V5	LMS: 11 m below BS	995.1	5/5-50 1/40 1/60	3	1/10 1/30 1/90		1	75	33
V6	LMS: 9 m below BS	997.1			1/26 1/50 1/70	1	N/A	0	33
V7	LMS: 5.5 m below BS	1000.3	1/60 1/90 1/-		1		1	0	33
V8	LMS: at contact with BS	1003.1 - 1005.9	4/20 1/30 1/40 1/60 5/-	14	3/5 3/10		3	100	50
V9	BS: 22.5 m below contact with UMS	1020.9				2	N/A	33	0
V10	BS: 17.5 m below contact with UMS	1025.6	1/4-12 1/30 1/40 1/190	3		1	1/4-12	57	50

NOTES:

- (1) LMS = Lower Mudrock Sequence
BS = Basal Sandstone
UMS = Upper Mudrock Sequence
- (2) Number of occurrences in drill holes and shaft within 0.5 m of reference elevation, adjusting for dip.
- (3) Thickness not given for SF2, SF4, CL features.
- (4) Number of actual occurrences/total possible number of occurrences.
- (5) Not applicable. This elevation not reached in shaft.

TABLE B10-3 (Cont'd)
ASSESSMENT OF SEAMS IN VALLEY BOTTOM

SEAM NO.	APPROXIMATE POSITION RELATIVE TO MAJOR GEOLOGIC CONTACTS (1)	REFERENCE ELEVATION AT DAM AXIS (m)	(2,3) STRUCTURAL FEATURES/THICKNESS (mm)					(4) RELATIVE OCCURRENCE IN SHELL OF DAM (3)	
			SF1	SF2	SF3	SF4	CL	SHAFT SSN	UPSTREAM DOWNSTREAM
V11	BS: 15.5 m below contact with UMS	1027.6	1/4-12 1/60			1	2	1/4-12	14 43
V12	BS: 12.5 m below contact with UMS	1030.7	1/50 1/110 6/-		1/10 1/20		2	1/10-30	67 29
V13	BS: 9 m below contact with UMS	1034.3	1/40 1/80		1/-		1		29 14
V14	BS: 5.5 m below contact with UMS	1037.6		3			1		29 0
V15	UMS: 1 m above BS	1043.9	1/30 1/34 1/7		5/5	1	1		50 0
V16	UMS: 3.5 m above BS	1046.8	1/7 1/10 1/160 1/-	1	1/1				56 0
V17	UMS: 4.5 m above BS	1047.7	1/50 1/130	4	2/5 1/10		2		44 40
V18	UMS: 6 m above BS	1049.4		4	2/7		1	1/1-2 1/8-32	40 0
V19	UMS: 7.5 m above BS	1050.5			2/20				33 0
V20	UMS: 8 m above BS	1051.4			1/4 1/20			1/10-18	67 25
V21	UMS: 11.5 m above BS	1054.5			1/140				0 25

NOTES:

- (1) LMS = Lower Mudrock Sequence
BS = Basal Sandstone
UMS = Upper Mudrock Sequence
- (2) Number of occurrences in drill holes and shaft within 0.5 m of reference elevation, adjusting for dip.
- (3) Thickness not given for SF2, SF4, CL features.
- (4) Number of actual occurrences/total possible number of occurrences.
- (5) Not applicable. This elevation not reached in shaft.

TABLE B10-4
CONTINUITY OF SEAMS IN VALLEY BOTTOM AREA,
UPSTREAM SHELL

SEAM	CONTINUOUS	DISCONTINUOUS
V1		X
V2	X	
V3	X	
V4		X
V5	X	
V6		X
V7		X
V8	X	
V9		X
V10	X	
V11		X
V12	X	
V13		X
V14		X
V15	X	
V16	X	
V17	X	
V18	X	
V19		X
V20	X	
V21		X

TABLE B10-5
CONTINUITY OF SEAMS IN VALLEY BOTTOM AREA,
DOWNSTREAM SHELL

SEAM	CONTINUOUS	DISCONTINUOUS
V1		X
V2		X
V3		X
V4	X	
V5		X
V6		X
V7		X
V8	X	
V9		X
V10	X	
V11	X	
V12		X
V13		X
V14		X
V15		X
V16		X
V17	X	
V18		X
V19		X
V20		X
V21		X



B11.0 ASSESSMENT OF SEAM THICKNESS

All other things being equal, the shear strength available along a relatively thick seam is less than that along a relatively thin seam, i.e., in the final assessment of the representative angle of shear resistance, thickness of the seams should be taken into account. The slightly greater shear strength available from thin seams can be attributed to the relatively greater contribution of the wall rock roughness during shear. Rock-to-rock contact is available in thin seams, but not in the thick seams.

Regarding the thicker seams mapped on site, detailed study indicated that although these seams were characterized by relatively high wall rock roughness, the actual planes of movement or shear surfaces usually were located in the centre part of the seam, i.e., the planes of movement within the seam were positioned in the most direct path of least resistance which was in the infilling, instead of following the wall rock. Hence, the geometry of the shear surface was flat in spite of wall rock roughness. For design purposes, therefore, it must be assumed that the shear characteristics of the thick seams will be those of the infilling and that the proximity of the wall rock will have little or no bearing on the shear strength of the seam. In this respect, there will be no positive shear strength contribution in the case of thick seams.

A criterion of 2 mm has been selected for the distinction of thick and thin seams, i.e., seams are designated thick if the SF3 or SSh-type features exceed or are equal to 2 mm in thickness. In subsequent sections, a small angle of shear strength will be added to the residual angle for the thin seams.

In the interest of conservative design, the 2 mm thickness dimension, and not some significantly greater thickness, is considered an appropriate criterion for the seam thickness assessment.

Accordingly, the seams which were designated continuous in the previous section, were assessed for thickness. Table B11-1 presents the results of this assessment for the spillway area. Of the continuous seams, ten were identified as thick and one was identified as thin.

Table B11-2 presents the analogous assessment for the seams in the upstream shell area of the dam foundation. In this case, eight seams were identified as thick and three as thin.

Table B11-3 presents the results for the seams in the downstream shell area. In this case, no seams were found to be thick and five were found to be thin.

TABLE B11-1
THICKNESS OF CONTINUOUS SEAMS IN SPILLWAY AREA

SEAM	THICK	THIN
R1	X	
R6	X	
R7		X
R8	X	
R9	X	
R10	X	
R13	X	
R14	X	
R15	X	
R16	X	
R17	X	

TABLE B11-2
THICKNESS OF CONTINUOUS SEAMS IN VALLEY BOTTOM AREA,
UPSTREAM SHELL

SEAM	THICK	THIN
V2	X	
V3		X
V5	X	
V8	X	
V10	X	
V12	X	
V15	X	
V16		X
V17	X	
V18		X
V20	X	

TABLE B11-3
THICKNESS OF CONTINUOUS SEAMS IN VALLEY BOTTOM AREA,
DOWNSTREAM SHELL

SEAM	THICK	THIN
V4		X
V8		X
V10		X
V11		X
V17		X



B12.0 DIRECT SHEAR TESTING

The following section outlines the laboratory testing and interpretation procedures involved in the drained direct shear testing of the undisturbed core samples from the shafts and drillholes. This information is summarized from Section 3.3, Appendix D, Volume 3 of the Preliminary Engineering Report, prepared by Thurber Consultants Ltd.

B12.1 DRAINED DIRECT SHEAR TESTING - CORE SAMPLES FROM DRILL HOLES - PEAK AND RESIDUAL STRENGTH

Direct shear tests were carried out on undisturbed samples of claystone or on samples of clay seams within more competent rock to determine both peak and residual shear strength parameters. Depending on the fracture pattern of the core to be tested, the samples were trimmed to 60 mm square specimens, 50 mm square or 50 mm diameter circular specimens or in a few cases, 45 mm diameter circular specimens. Most of the testing was carried out on 50 mm diameter circular specimens.

The test procedure followed in the direct shear testing program was as follows:

- The sample was consolidated to the desired normal stress in two equal increments.
- t_{50} was determined in the second stage of that consolidation.

- The time to failure was determined as recommended in ASTM Designation D3080, "Direct Shear Test of Soils Under Consolidation Drained Conditions."

$$\text{i.e., } t_f = (50 \times t_{50})$$

- The rate of shearing was calculated assuming a displacement to peak failure of 2 mm.
- Generally the calculated rate of shearing determined by ASTM methods was between 0.4 mm/min. and 0.02 mm/min., which was considered to be too fast. The rate of shearing during peak strength testing was therefore slowed to 0.0048 mm/min., which is on average a ten-fold decrease. In all of the tests the peak strength shearing rate was slower than that calculated by ASTM Designation D3080.
- Having determined peak strength, at least five fast residual cycles were run at a rate of 0.18 mm/min.
- The test was then stopped for t_{100} or 12 hours, whichever was longer
- To complete the test, two slow residual cycles were run at rates in order of 0.016 mm/min. If the 0.016 mm/min. rate was faster than the calculated ASTM rate, then a comparison was made between the cycles at the 0.016 mm/min. rate and the last two cycles at 0.18 mm/min. for evidence of shear strength increase due to incomplete pore pressure dissipation. If such evidence was found, then the two further cycles were done at the ASTM rate.

Considerable care was taken during testing to minimize the influence of potential excess pore pressure on the drained direct shear test results. To achieve this, the tests were conducted at slower rates of shearing relative to ASTM standard procedures for drained tests. Examination of the test results indicates that excess pore pressure, if at all generated, did not influence the shear strengths measured. If excess pore pressures were generated on the failure plane during the fast residual cycles, an increase in the residual shear stress would be anticipated during the two slow residual cycles as a result of dissipation of the pore pressures. No such increase in shear strength was observed in any of these tests.

Due to the nature of the claystone and clay seam materials tested, irregular, non-planar shear surfaces frequently developed during testing and resulted in "ramping" (regular upward and downward movement of the top of the sample). (BCHPA (1971), Barton and Choubey (1977), Patton (1961), Nicholson (1983), Ripley and Lee (1961), Martin and Millar (1974)). This ramping behavior became most pronounced during the residual strength determination phase of the test.

The ramping can best be observed in the horizontal versus vertical displacement data plot. It is noted that ramping did not occur in every test carried out.

The frequency and amplitude of the cyclic movement obtained from the horizontal versus vertical displacement plots gives an indication of the shape of the failure planes and this can later be confirmed by observations when the sample is broken apart on completion of the test. For example, a concave/convex failure plane will produce both upward and

downward movement during one shearing cycle, whereas a linear but inclined failure plane will produce downward movement during one cycle and upward movement during the other cycles.

Ramping can have a significant effect on the residual strength test results. When the top of the sample is moving upwards, additional work is done to raise the normal load acting on the sample. The additional work is reflected in a higher measured shear stress, thereby increasing the apparent ϕ' . When the top of the sample is moving downwards, the applied normal load adds energy to the system, thereby decreasing the apparent ϕ' . It is necessary to provide a correction for these shear plane geometry effects when interpreting the direct shear test results.

The shape of the shear stress versus horizontal displacement plot is greatly affected by ramping. A review of these data plots reveals some relatively consistent general correlations between the shape of the failure plane and the shear stress versus horizontal displacement plot obtained from the test. The correlations fall into one of the following three categories:

- The shear stress versus horizontal displacement plot stabilized (i.e., remained at a relatively constant value throughout a cycle) in both directions of shearing. Any difference in magnitude between tension and compression cycles could be interpreted as a result of ramping and the data corrected to make allowance for the ramping. The correction applied to account for ramping is detailed below.

- The shear stress versus displacement curve stabilized in one direction of shearing yet failed to stabilize in the other. Invariably, the shear stress versus displacement plot tends to stabilize when the top half of the sample is riding upwards and fails to stabilize when the top half is riding downward.
- The shear stress versus displacement plot failed to stabilize in either direction. The results of these tests are treated with less confidence than the other data.

The effects of ramping on the test data can be treated as an asperity correction as described by Patton (1966) and Hoek and Bray (1977). The correction procedure equates the frictional resistance and energy balance of a block sliding along an inclined plane. It is shown that for small angles of inclination the sliding friction equation is reduced to:

$$\tau = \sigma_n' \tan (\phi' + i)$$

Where:

- τ = shear resistance of the plane
- σ_n' = effective normal stress on the failure plane
- ϕ' = friction angle
- i = inclination of the plane

An estimate of the friction angle $\phi'r$ is obtained by adding a correction for inclination of the failure plane (obtained from the horizontal versus vertical displacement plot) to the apparent $\phi'r$ value obtained from the shear stress versus displacement plot. The correction can be determined for either the upward or downward movement.

The $\phi'r$ obtained in this manner is the value one would expect to observe for this material if the failure plane was horizontal. The tests exhibiting ramping behaviour were corrected in the foregoing fashion to obtain an interpreted value of $\phi'r$. For most tests, there is a high degree of confidence in the interpreted results. As noted previously, the results of test where the shear stress versus displacement plot failed to stabilize in either direction are treated with less confidence than the other data.

B12.2 DRAINED DIRECT SHEAR TESTING - CORE SAMPLES FROM DRILL HOLES
- MULTI-STAGE RESIDUAL

One multi-stage rate, multi-stage direct shear test was carried out to investigate the following:

1. The effects of variable rates of shearing on the mobilized shear stress, and
2. Definition of the apparent curvature of the residual strength failure envelope observed in some tests.

In the first stage of this test, 10 residual cycles were run at a normal load of 250 kPa at three different rates of shearing. In addition, the test was temporarily stopped for up to 12 hours to permit dissipation of any pore pressures which may have been generated on the failure plane.

The second stage consisted of 14 residual cycles run at a normal load of 500 kPa at three different shearing rates with two stops for pore pressure dissipation.

In the third stage, eight residual cycles were run at a normal stress of 1000 kPa at two different rates of shearing. The fourth stage consisted of five cycles run at a normal stress of 1500 kPa at two different rates of shearing.

Examination of the shear stress versus displacement plots for all normal stress levels indicates that the differing rates of shearing had no effect on the shear stresses measured. Furthermore, in these test stages at least 2 were run at the very slow shear rate of 0.0048 mm/min. after a 12-hour period of quiescence for pore pressure dissipation. With these procedures it would be unreasonable to expect any excess pore pressures on the failure plane during the slow cycles. Since the shape and magnitude of the fast cycles in each test are virtually identical to that observed during the slow (0.0048 mm/min.) cycles, the test results indicate that excess pore pressures had not been generated during the fast cycles at 0.18 mm/min. or at 0.016 mm/min.

This agreement between the residual strength envelope for this multi-stage test and that obtained from a normal direct shear test is excellent. The slight curvature observed in the normal test at low normal stresses was confirmed by the multi-stage test.

B12.3 DRAINED DIRECT SHEAR TESTING - SHAFT SAMPLES - PEAK AND RESIDUAL STRENGTH

Direct shear tests were carried out on approximately 80 mm square claystone specimens containing thin clay seams. The specimens were carefully cut and trimmed from the 193 mm diameter core samples taken from the shaft walls. The

specimens were grouted into a 100 mm square shear box using a quick setting cement fondue. Care was taken to align the clay seams with the split between the two halves of the shear box and to align the sample such that the axis of shearing in the test was coincident with the potential direction of shearing in the field.

With the exception of two tests, ramping was not observed during shearing. In most cases, extrusion of the weak soft clay seam material and consequent "settlement" of the load cap was observed.

In many of these tests the lowest measured value of shear stress was observed during the first cycle with the measured shear stresses tending to increase with further displacement. This behaviour has been attributed to extrusion of the clay seam material during testing. Since the clay seams were generally thin and of a contorted non-planar geometry, it is postulated that as the weak pre-sheared clay seam material was extruded, the stronger adjacent rock faces came into contact and the measured shear stresses increased due to interference at the contact. This interpretation is supported by observations of the shear planes after testing which frequently indicated that the stronger rock faces had come into contact over portions of the failure surface.

The irregular non-planar geometry of the clay seams resulted in adverse effects to the direct shear tests of some samples.

As these tests progressed, the top half of the shear box underwent rotation and lateral displacement normal to the axis of shearing, causing progressive misalignment of the upper and lower halves of the shear box. The misalignment was considerable and in some tests the magnitude of the lateral displacement perpendicular to the axis of shearing was about equal to the axial displacement. Examination of the failure planes on completion of these tests indicated that this behaviour resulted from interference between the irregular faces of the strong intact rock on either side of the clay seam, i.e., the two halves of the sample preferentially rotated about the point of interference instead of shearing through the intact rock to eliminate the interference. The overall result of such misalignment was to cause an eccentricity in the frame used to apply the normal load to the sample.

The direct shear apparatus is known to be sensitive to eccentricities; however, since it is not possible to quantify these effects, these results must be regarded as suspect. Since these tests gave abnormally low values of ϕ' relative to all other direct shear tests in this program and since there is no apparent difference in the index properties for these seams compared to the others tested, it is believed that the eccentricities have been responsible for the unusually low ϕ' results. This suggests that the eccentricities interfered with the normal load application mechanism and have reduced the actual normal load applied to the sample.

B12.4 TEST RESULTS

Geological interpretation indicates that the seams result predominantly from the stress-deformation history of the

project site and are due primarily to tectonic and valley rebound phenomena, rather than to the presence of weaker clay materials or a higher clay content than found in the immediately adjacent rock. As a result, it is considered that there are no beds of unsheared material on site whose strength is less than the strength of the sheared seams. This is borne out by the results of the direct shear box tests on specimens of seams and adjacent unsheared claystone taken from drill core and from the core samples taken from the walls of the shaft. These showed that the silty clay and clay materials in seams have the same residual strength as adjacent claystones of similar mineral composition. As a consequence of the shear deformation that has occurred in situ, the seams exhibit considerably lower peak strengths and higher natural moisture contents than in the adjacent unsheared claystone. Also, where seams are found in drill core that are too disturbed to test in the shear box, a test on the intact rock above or below the seam is a valid indicator of the residual shear strength of the seam.

The shear strength of seams was measured in direct shear using the laboratory shear box apparatus and following the procedures described in the previous section. Both seam material and the intact rock adjacent to the seams were tested. The results are summarized in Table B12-1. The individual test result and Mohr plots for the individual seam from a particular location are shown on Plates B-37 to B-102.

12.5 RESIDUAL SHEAR STRENGTH CORRELATIONS

A number of standard correlations of residual shear strength against index properties were studied to determine if there was a simpler means of identifying the weaker parts of the

rock. Correlations for the seams are shown on Plates B-99 to B-101. The data are also plotted using the grouping of test data within bands described elsewhere in the text. These are shown on Plates B-49 to B-64. It can be seen that there is a better correlation if only the seam data are used. Even with those plots only a lower bound curve can be drawn, the use of which is restricted to considering worst case scenarios.

The plots show the variation of the residual angle of shearing resistance with the following index properties:

- liquid limit
- clay content
- plasticity
- activity

The correlations between the residual angle of shearing resistance and the liquid limit, the clay content and the plasticity index are somewhat better than those between the residual angle of shearing resistance and activity. (Skempton (1964), Townsend and Gilbert (1974)).

Generally, with increasing clay content, liquid limit and plasticity index, the residual angle of shearing resistance decreases.

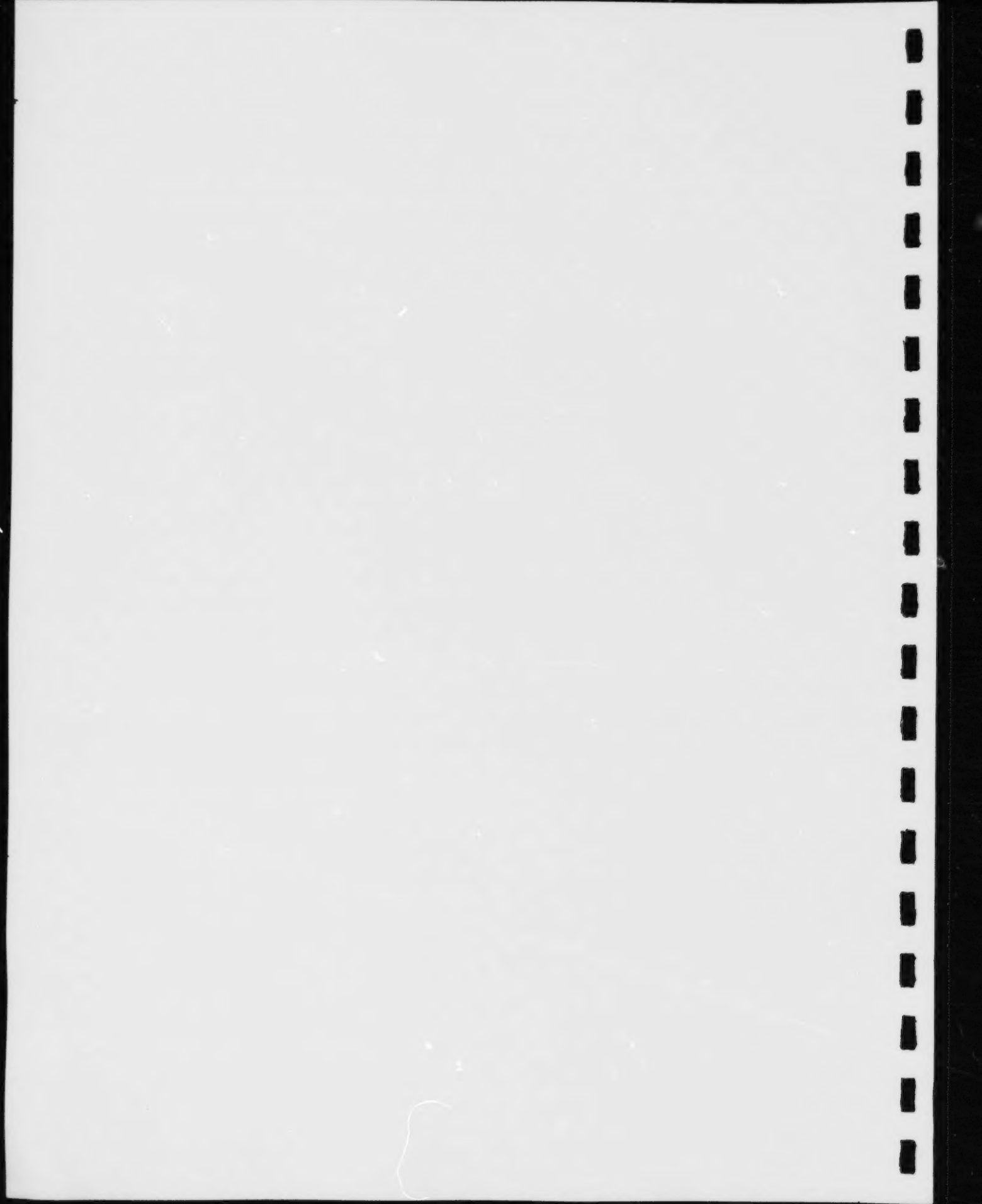


TABLE B12.1

DIRECT SHEAR TEST RESULT (1)

SHAFT/ DRILLHOLE NO.	SAMPLE NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTENBERG LIMITS LL PL PI	GRAIN SIZES (%) CLAY SILT SAND	ACTIVITY	NORMAL IN SITU SHEAR	RESIDUAL SHEAR	β IN SITU	β_r (GROUP) (DEC.)	MATERIAL TESTED	
STRATA ELEVATION: BELOW 1000 m													
BC-46-04258	3	27.2	1025.03	12.5	46.7 : 24.9	21.4 60	0	0.36	300	213.9	124	35.5	
BC-46-04258	3	To	1024.90	12.0	46.7 : 24.9	21.4 60	0	0.36	800	432.8	190	28.4	
BC-46-04258	3	27.33	1024.90	12.5	46.7 : 24.9	21.4 60	0	0.36	1300	697.6	300	20.2	
BC-46-0415	9	25.73	1031.73	16.2	40.5 : 20.2	20.3 48	0	0.42	400	296.5	115	36.5	
BC-46-0415	10	25.99	1031.47	10.2	37.7 : 18.7	19.0 30	0	0.43	400	538.8	349	34.0	
BC-46-0415	12	26.56	1030.90	9.2	36.5 : 19.0	17.5 44	55	1	0.40	1200	661.1	360	28.9
BC-45-0778	5	26.46	1025.20	14.5	38.3 : 18.1	20.2 35	55	10	0.58	500	332.6	160	33.6
BC-45-0778	5	To	1024.83	13.2	38.3 : 18.1	20.2 35	55	10	0.58	1000	719.1	261	35.7
BC-45-0778	5	26.43	1024.83	15.1	38.3 : 18.1	20.2 35	55	10	0.58	1500	763.1	370	27.6
BC-45-08	8	22.16	1029.32	17.9	34.0 : 16.2	17.8 42	49	9	0.42	500	278.5	175	29.1
BC-45-08	9	24.60	1026.46	15.9	34.0 : 16.2	17.8 42	49	9	0.42	500	376.4	235	37.0
BC-45-08	9	To	1026.46	15.9	34.0 : 16.2	17.8 42	49	9	0.42	1000	585.7	340	30.4
BC-45-08	9	24.40	1026.46	7.4	34.0 : 16.2	17.8 42	49	9	0.42	1500	1136.5	637	37.1
BC-45-010	14	69.95 To	1003.45 To	11.7	42.7 : 22.7	20.0 20	61	19	1.00	427	521.0	149	32.2
BC-45-010	14	70.10	1003.35	8.4	42.7 : 22.7	20.0 20	61	19	1.00	1500	1028.8	325	34.4
BC-45-65	6	28.38	1029.40	6.1	36.9 : 16.9	20.0 29	70	1	0.49	500	1162.2	240	66.7
BC-45-65	6	To	1029.40	6.1	36.9 : 16.9	20.0 29	70	1	0.49	1000	1399.2	400	54.4
BC-45-65	6	28.40	1028.91	6.1	36.9 : 16.9	20.0 29	70	1	0.49	1500	1661.8	650	47.9
BC-45-658	7	22.82	1030.25	4.0	27.3 : 15.2	12.1 32	66	2	0.38	500	1633.7	261	73.0
BC-45-658	7	22.44	1030.23	4.0	27.3 : 15.2	12.1 32	66	2	0.38	1000	2093.6	563.4	64.5
BC-45-658	7	22.40	1030.27	4.0	27.3 : 15.2	12.1 32	66	2	0.38	1500	2669.2	751.1	62.4
BC-45-012	24	35.0	1019.3	4.3	28.5 : 17.6	10.9 18	64	18	0.61	500	299.6	222.7	30.9
BC-45-010	5	30.9	1031.46	3.4	28.1 : 17.5	10.6 24.5	64.5	11.0	0.43	500	1101.9	250.6	67.1
BC-45-010	5	30.65	1031.23	1.3	43.9 : 22.7	21.2 20	45	27	0.76	1000	1929.3	393.2	62.6
BC-45-010	8	43.39	1022.22	4.5	30.9 : 20.7	14.2 37.5	59.5	3.0	0.49	500	1300.1	237.0	70.1
BC-45-010	10	46.65	1019.97	8.5	40.4 : 20.7	19.7 42	55	3	0.47	500	1086.9	127.4	64.7
BC-45-010	10	46.75	1019.45	7.5	40.4 : 20.7	19.7 42	55	3	0.47	1000	1322.6	310.0	52.9
BC-45-010	10	46.70	1019.40	7.3	40.4 : 20.7	19.7 42	55	3	0.47	1500	1735.5	400.0	49.0
SB-45-095	10C	38.7	1031.25	14.9	42.1 : 22.6	19.5 57	43	0	0.34	500	167.7	135	10.5
SB-45-095	10A	38.7	1031.25	13.9	41.7 : 21.1	20.6 54	46	0	0.38	1000	204.3	204	11.5
SB-45-095	10B	38.7	1031.25	13.0	42.6 : 22.5	20.1 55	45	0	0.37	1500	240	290	10.9

TABLE B12.1 CONTINUED (2)

SHAFT/ DRILLHOLE NO.	SAMPLE NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTERBERG LIMITS			GRAIN SIZES (%)			ACTIVITY	NORMAL IN SITU SHEAR	EFFECTIVE STRESS (kPa)			ρ_c (g/cm ³) TEST	ρ_c (g/cm ³) (OBS.)	MATERIAL TESTED
					LL	PL	PI	CLAY	SILT	SAND			IN SITU SHEAR					
STRATA ELEVATION: BELOW 1040 m Continued																		
SR-05-005	4C	39.15	1030.40	-	40	24	16	47	52	1	0.34	500	110	110	12.4	12	585	
SR-05-005	4C	39.15	1030.40	-	40	24	16	47	52	1	0.34	1000	262	210	16.7	11.9		
SR-05-005	11B	44.36	1025.59	12.8	35.0	20.6	14.4	33	66	1	0.44	500	153	140	17.0	15.6		
SR-05-005	11B	44.36	1025.59	12.8	35.0	20.6	14.4	33	66	1	0.44	1000	309	296	17.2	16.5	14.7	
SR-05-005	11B	44.36	1025.59	12.8	35.0	20.6	14.4	33	66	1	0.44	1500	410	350	15.6	13.1		
SR-05-005	4D	42.03	1027.92	9.7	36.4	21.2	15.2	40	57	3	0.30	500	245	135	26.1	15.1	545	
SR-05-005	4C	42.03	1027.92	9.0	31.4	20.6	10.0	32	67	1	0.34	1000	400	300	22.2	16.7	585	
SR-05-005	4C	42.03	1027.92	9.0	31.4	20.6	10.0	32	67	1	0.34	1500	505	344	21.3	14.4		
STRATA ELEVATION: 1040 to 1050 m																		
RC-05-010	1	6.26	1046.01	6.4	30.2	15.9	14.3	10	70.5	3.5	0.79	200	702.8	107.5	74.1	20.3		
RC-05-010	1			6.4	30.2	15.9	14.3	10	70.5	3.5	0.79	200	831.7	18.9	76.5	20.2		
RC-05-010	1	To		6.4	30.2	15.9	14.3	10	70.5	3.5	0.79	500	1145.6	235.5	66.4	25.2	24.9	
RC-05-010	1			6.4	30.2	15.9	14.3	10	70.5	3.5	0.79	500	1538.6	272.6	72.0	20.6		
RC-05-010	1	6.51	1046.56	6.4		15.9	14.3	10	70.5	3.5	0.79	1000	2476.4	373.2	55.9	20.5		
RC-05-010	1			6.4		15.9	14.3	10	70.5	3.5	0.79	1500	3207.3	855.5	64.9	29.3		
RC-05-010	2	9.00	1046.07	6.4	35.4	19.8	15.6	32	67	1	0.49	200	609.6	77.6	73.8	21.2		
RC-05-010	2			6.4	35.4	19.8	15.6	32	67	1	0.49	500	905.9	202.2	61.1	22.0		
RC-05-010	2			6.4	35.4	19.8	15.6	32	67	1	0.49	1000	1402.6	340.0	59.3	10.8		
RC-05-010	2			6.4	35.4	19.8	15.6	32	67	1	0.49	1000	1651.2	350.0	55.4	19.3		
RC-05-010	2	To		6.4	35.4	19.8	15.6	32	67	1	0.49	1500	1621.6	405.0	47.2	10.3	19.5	
RC-05-010	2			6.4	35.4	19.8	15.6	32	67	1	0.49	1500	1946.2	470.0	52.4	17.4		
RC-05-010	2			6.4	35.4	19.8	15.6	32	67	1	0.49	250	571.2	122.0	66.4	26.0		
RC-05-010	2			6.4	35.4	19.8	15.6	32	67	1	0.49	500	-	202.0		22.0		
RC-05-010	2			6.4	35.4	19.8	15.6	32	67	1	0.49	1000	-	307.0		21.2		
RC-05-010	2	9.41	1043.66	6.4	35.4	19.8	15.6	32	67	1	0.49	1500	-	531.0		19.5		
RC-05-012	2	13.30 To	1041.0 To	5.7	36.7	20.2	16.5	47.5	51.5	1.0	0.35	250	701.1	109.5	70.4	23.7	22.4	
RC-05-012	2	13.56	1040.74	5.7	36.7	20.2	16.5	47.5	51.5	1.0	0.35	500	1045.1	206.1	64.4	22.4		CS
RC-05-012	3	14.90 To	1039.4 To	6.4	35.5	18.4	16.7	35	64	1	0.40	250	1042.1	143.2	76.5	20.4	23.7	
RC-05-012	3	15.20	1039.1	6.4	35.5	18.4	16.7	35	64	1	0.40	500	1596.8	219.7	72.6	23.7		
RC-05-010	4	7.97 To	1045.32 To	12.0	46.6	22.9	23.7	46	54	0	0.47	300	350.8	44.9	50.1	15.4	15.4	CS
RC-05-010	4	8.37	1044.92	16.2	46.6	22.9	23.7	46	54	0	0.47	407	634.3	133.5	51.9	15.0		
RC-05-010	3	14.67	1042.53	17.4	34.4	18.9	15.9	38.5	50.5	2	0.4	500	422.5	275.0	40.2	20.4		CS

TABLE B12.1 CONTINUED (3)

SHAFT/ DRILLHOLE NO.	SAMPLE NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTENBERG LIMITS			GRAIN SIZES (N)			ACTIVITY: NORMAL	EFFECTIVE STRESS (kPa)		REGIONAL:		ρ' (DEC.)	MATERIAL TESTED
					LL	PL	PI	CLAY	SILT	SAND		NORMAL	IN SITU	SHEAR			
STRAT ELEVATION: 1040 to 1050 m Continued																	
SR-45-095	1A	20.53	1049.4	12.3	36.0	22.2	13.0	42.5	56.7	0.8	0.33	500	136.0	15.2	136.0	15.2	SMS
SR-45-095	1A	20.53	1049.4	12.3	36.0	22.2	13.0	42.5	56.7	0.8	0.33	1000	310.0	17.2	200.0	15.6	SMS
SR-45-095	1B	20.55	1049.4	7.7	35.0	22.0	13.0	41	56.2	0.8	0.32	1500	337.0	12.7	337.0	12.7	SMS
SR-45-095	6A	20.48	1049.07	11.8	29.6	20.0	9.6	34	62	4	0.28	1500	670.0	24.1	560.0	20.5	SMS
SR-47-014	7A	10.45	1046.42	14.4								1050	452	23.3	240	14.9	SMS
SR-47-014	7A	10.45	1046.42	14.4	47.5	21.9	25.3					350	222	32.6	92	14.7	SMS
SR-47-014	7A	10.45	1046.42	14.4								750	373	19.4	154	14.5	SMS
SR-47-014	7B	10.45	1046.42		44.4	23.4	21.0					750	490	20.0	200	15.0	SMS
SR-47-014	7B	10.45	1046.42					24*	74	2.0		1050	450	23.2	395	15.7	SMS
SR-45-095	6B	20.48	1049.07	10.6	33.1	23.3	9.8	36	61	3	0.27	1000	499.0	26.5	400.0	23.7	SMS
SR-45-095	6B	20.48	1049.07	10.6	33.1	23.3	9.8	36	61	3	0.27	1000	380.0	20.0	300.0	20.0	SMS
SR-45-095	6B	20.56	1049.01	10.3	34.4	22.6	11.8	39	60	1	0.30	500	277.0	19.0	100.0	19.0	SMS
CR-47-4359	2B	61.84	1048.9		32.5	14.6	17.9	30	62	8	0.40						
CR-47-752	35	87.35	1048.68		30.9	17.4	21.5	43.5	51.5	5.0	0.49						CS
CR-47-752	35	87.40	1048.43		34.0	17.0	17.0	33.0	55.0	12.0	0.52						MS
SR-47-014	7A	10.45	1046.42		35.0*	20.5	15.3	27.5*	67.1	5.4	0.56						SMS
SR-47-014	7A	10.45	1046.42		37.0*	19.6	17.4	28.5*	66.4	11.1	0.61						CS-L
SR-47-014	7A	10.45	1046.42		22.0*	16.3	5.7	11.0*	66.0	21.0	0.52						CS-L
SR-47-014	7A	10.45	1046.42		20.9	16.7	12.2										CS-L
SR-47-014	7A	10.45	1046.42	10.1	49.0	22.9	26.1										CS-L
SR-47-014	8A	11.77	1045.90									1050	520	26.3	245	15.2	SMS
SR-47-014	8A	11.77	1045.90									650	290	24.0	241	20.3	SMS
SR-47-014	7B	10.45	1046.42		43.4	22.0	20.6	19.0*	76	5							CS-L
SR-47-014	7B	10.45	1046.42		30.2	16.4	13.4	6.0*	76	10							CS-L
SR-47-014	8A	11.77	1045.90		30.9	16.9	14.0										CS-L
SR-47-014	8A	11.77	1045.90		23.3*	17.1	6.2	5*	46	9	1.24						CS-L
SR-47-014	8A	11.77	1045.90		23.0*	17.2	6.6	6*	82	12	1.10						CS-L
SR-47-014	8A	11.77	1045.90		33.4	14.7	14.7										CS-L
SR-47-014	8A	11.77	1045.90		31.4*	18.0	13.4	12*	10	98	1.13						CS-L
SR-47-014	8A	11.77	1045.90		29.4	16.4	13.0										CS-L

TABLE 812.1 CONTINUED (6)

SHAFT/ BELLHOLE NO.	SAMPLE NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTENBERG LIMITS				GRAIN SIZES (N)				ACTIVITY	NORMAL: IN SITU	EFFECTIVE STRESS (kPa)	RESIDUAL: SHEAR	β' IN SITU (DEG.)	β' (DEG.)	β' (GROUP) (DEG.)	MATERIAL TESTED
					LL	PL	PI	CLAY	SILT	SAND	CLAY	SILT								
STRATA ELEVATION: 1050 m to 1005 m Continued																				
CR-07-8759	14	36.42	1071.52	16.9	45.2	22.8	22.4	51	48	1	0.46	450	523.6	150.0	49.9	10.4			CS	
CR-07-8756	19	63.87	1067.10	16.1	53.2	25.8	27.4	57	42	1	0.40	1150	663.8	240.0	30.0	11.0	10.9		CS	
CR-07-8751	7	69.77	1067.55	12.5	50.0	23.5	26.5	62	37	1	0.43	1250	655.5	220.0	20.0	10.0			CS	
CR-07-8750	10	52.33	1066.40	12.9	51.1	24.2	26.9	67	32	1	0.40	1350	674.6	255.0	19.4	10.7			SND	
CR-07-8759	15	61.20	1064.74	14.9	49.1	24.7	24.6	61	36	1	0.40	550	253.1	115.0	24.2	11.4	10.0		SND	
CR-07-8750	13	67.40	1069.49	17.0	54.4	25.1	29.3	66	33.5	0.5	0.44	950	106.5	145.0	11.1	8.7			SND	
CR-07-8753	14	60.79	1069.41		55.0	23.3	31.7	70	36	0	0.45									
DT-05-675	1		1065.69	16.6	60.4	25.0	35.6	67	32	1	0.53	450	139.7	105	17.2	13.1			SMS	
DT-05-675	1		1065.69	17.2	60.4	25.0	35.6	67	32	1	0.53	1050	326.4	220	17.2	11.0	11.5			
DT-05-675	1		1065.69	14.9	60.4	25.0	35.6	67	32	1	0.53	1250	337.5	240	15.1	10.9				
DT-05-675	1		1065.69	16.7	60.6	25.0	35.6	67	32	1	0.53	850	264.1	185	17.3	12.3			SMS	
DT-05-675	2		1065.69	20.6	64.1	25.4	34.7	65	34.5	0.5	0.6	750	125.4	87	19.7	14.0			SMS	
DT-05-675	2		1065.69	10.1	64.1	25.4	34.7	65	34.5	0.5	0.6	750	240.0	145	17.3	10.9			SMS	
DT-05-675	2		1065.69	17.6	64.1	25.4	34.7	65	34.5	0.5	0.6	1150	351.2	230	17.1	11.3			SMS	
DT-05-675	3		1065.72	10.6	57.0	25.1	32.7	62	37	1	0.53	350	119.5	83	14.9	13.3			SMS	
DT-05-675	3		1065.72	15.2	57.0	25.1	32.7	62	37	1	0.53	1150	404.2	260	19.4	12.7			SMS	
DT-05-675	3		1065.72	14.5	57.0	25.1	32.7	62	37	1	0.53	750	280.8	160	21.2	12.0			SMS	
DT-05-675	3		1065.72	17.0	57.0	25.1	32.7	62	37	1	0.53	950	284.2	195	16.9	11.0			SMS	
DT-05-675	3		1065.72	13.9	57.0	25.1	32.7	62	37	1	0.53	1350	482.2	280	15.7	11.7			SMS	
DT-05-675	3		1065.72	21.0	57.0	25.1	32.7	62	37	1	0.53	550	174.7	144	17.6	14.7			SMS	
DT-05-675	4		1065.72	21.0	60.3	24.8	35.5	60.1	29.0	31.1	0.59	450	163.0	90	19.9	12.3			SMS	
DT-05-675	4		1065.72	21.2								550	156.7	106	16.1	10.9			SMS	
CR-07-8750	14	70.87	1066.42		31.4	14.7	16.7	32	65	3	0.52								CS	
CR-07-8750	14	70.82	1066.37		30.9	13.8	15.1	23	70	7	0.46								SND	
CR-07-8750	14	70.82	1066.37		22	15	7	15	83	2	0.47								MS	
CR-07-8750	17	83.46	1053.83		44	22	22	50	50	0	0.44									
CR-07-8750	17	83.47	1053.82																	
CR-07-8751	15	63.40	1072.73		30.0	20.0	19.0	45	55	0	0.40									
CR-07-8751	8	73.00	1066.14		34.1	17.7	16.4	23	72	5	0.71									
CR-07-8751	9	75.89	1061.33		35.2	20.2	15.0	39	59	1.2	0.38									
CR-07-8751	14	60.79	1069.41	17.1	55	20.3	31.7	70	30	0	0.45	1050	355.5	165	10.7	8.9			SND	
CR-07-8750	20	64.87	1067.16		32.7	17.2	15.5	35	64	1	0.40									
CR-07-8755	10	60.53	1070.76		46	22	22	54	46	0	0.41									
CR-07-8755	11A	60.60	1062.69		23	15	0	30	62	0	0.27									
CR-07-8755	11B	60.66	1062.63		27.6	15.4	12.2	21.5	69.5	9	0.37									
CR-07-8755	11C	60.71	1062.50		30.1	16.3	12.8	19	71	10	0.73									
CR-07-8756	12	50.40	1071.47		47	19	23	53	46.5	0.5	0.43									
CR-07-8756	13	52.94	1066.37	16.2	52	25	27	61	37	2	0.40	650	233.0	163	15.4	11.0			SND	

TABLE B12.1 CONTINUED (SI)

DEPTH (m)	SAMPLE NO.	ELEVATION (m)	WATER CONTENT (%)	ATTENDING LIMITS LL : PL : PI	GRAIN SIZES (N)	CLAY : SILT : SAND	ACTIVITY	NORMAL : SHEAR	EFFECTIVE STRESS (kPa)	RESIDUAL: SHEAR	σ'_v IN SITU	σ'_v (GROUP) (OBS.)	σ'_v (CALC) (TEST)	MATERIAL TESTED
STRATA ELEVATION: 1050 m to 1065 m Continued														
1044.5	CR-07-0757	1044.5	51	23 : 29	52.5 : 47.5	0	0.55							
1044.33	CR-07-0757	1044.33	44.4	23.4 : 20.6	41	57	2	0.50						
1043.58	CR-07-0757	1043.58	31	17 : 14	31	65	4	0.45						
1043.18	CR-07-0757	1043.18	33.1	15.4 : 17.7	40.5	59	0.5	0.44						
1042.40	CR-07-0757	1042.40	35.5	17.1 : 18.4	41	58.5	0.5	0.45						
1042.2	CR-07-0757	1042.2	44	21.9 : 22.1	48	52	0	0.46						
1041.11	CR-07-0758	1041.11	45	25 : 30	57	42	1	0.35						
1040.28	CR-07-0758	1040.28	39	20 : 19	55	44.5	0.5	0.35						
1040.04	CR-07-0758	1040.04	38.9	19.2 : 19.7	54	46	0	0.36						
1039.48	CR-07-0758	1039.48	38.7	18.4 : 22.3	44	56	0.4	0.51						
1037.33	CR-07-0759	1037.33	35.2	19.6 : 15.6	36	64	0.0	0.43						
1061.38	ACCESS ROAD : AR-3	1061.38	51.9	25.9 : 26.0	60.0	40	0.0	0.43						SMS
1062.92	ACCESS ROAD : AR-7	1062.92	52.9	31.4 : 21.1	59.0	31.0	0.0	0.31						SMS
1062.98	ACCESS ROAD : AR-11	1062.98	46.2	23.4 : 20.8	46.0	52.0	2.0	0.45						SMS
1063.00	ACCESS ROAD : AR-9	1063.00	53.8	26.3 : 25.3	55.0	41.0	0.0	0.43						SMS
1061.56	ACCESS ROAD : AR-1	1061.56	56.1	27.8 : 28.3	63.0	37.0	0.0	0.45						SMS
1073.13	CR-05-018	1073.13	51	23 : 20	43	56	1	0.65	500	677.9				CS
1072.63	CR-05-018	1072.63	51	23 : 20	43	56	1	0.65	1000	1357.5				CS
1070.76	CR-05-018	1070.76	50	-	-	-	-	-	1500	1612.9				CS
1070.27	CR-05-018	1070.27	50	-	-	-	-	-	500	978.4				CS
1070.27	CR-05-018	1070.27	50	-	-	-	-	-	1000	1077.0				CS
1070.27	CR-05-018	1070.27	50	-	-	-	-	-	1500	1853.4				CS
1069.9	CR-05-0764	1069.9	55.7	46.2 : 19.5	24.3	48	52	0	0.51	600	271.1			SMS
1067.97	CR-05-0767	1067.97	47.8	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	400	50.1			SMS
1067.97	CR-05-0767	1067.97	47.9	48.1 : 25.2	22.9	60.5	39.0	0.5	0.38	450	140.1			SMS
1067.97	CR-05-0767	1067.97	46.4	46.5 : 23.4	23.1	60.5	39.0	0.5	0.36	700	180.3			SMS
1067.97	CR-05-0767	1067.97	45.8	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	1000	282.9			SMS
1067.77	CR-05-0767	1067.77	46.4	52.7 : 22.8	28.9	70	30	0	0.43	400	79.2			SMS
1067.77	CR-05-0767	1067.77	45.6	52.7 : 22.8	28.9	70	30	0	0.43	700	136.0			SMS
1067.77	CR-05-0767	1067.77	45.3	52.7 : 22.8	28.9	70	30	0	0.43	1000	282.1			SMS
1067.04	CR-05-0767	1067.04	46.4	44.6 : 23.7	28.9	60	40	0	0.35	400	176.5			SMS
1067.04	CR-05-0767	1067.04	46.9	44.6 : 23.7	28.9	60	40	0	0.35	700	310.4			SMS
1067.04	CR-05-0767	1067.04	48.3	46.4 : 24.8	21.6	55	45	0	0.39	800	287.8			SMS
1073.7	CR-05-0764	1073.7	57	46.2 : 19.5	24.3	48	52	0	0.51	600	271.1			SMS
1072.63	CR-05-0764	1072.63	57	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	400	50.1			SMS
1070.76	CR-05-0764	1070.76	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.36	700	180.3			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	1000	282.9			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	1500	433.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	2000	584.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	2500	736.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	3000	887.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	3500	1039.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	4000	1190.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	4500	1341.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	5000	1493.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	5500	1644.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	6000	1796.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	6500	1947.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	7000	2098.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	7500	2250.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	8000	2401.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	8500	2553.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	9000	2704.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	9500	2855.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	10000	3007.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	10500	3158.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	11000	3310.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	11500	3461.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	12000	3612.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	12500	3764.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	13000	3915.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	13500	4067.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	14000	4218.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	14500	4369.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	15000	4521.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	15500	4672.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	16000	4824.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	16500	4975.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	17000	5126.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	17500	5278.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	18000	5429.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	18500	5581.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	19000	5732.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	19500	5883.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	20000	6035.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	20500	6186.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	21000	6338.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	21500	6489.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	22000	6640.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	22500	6792.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	23000	6943.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	23500	7095.0			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	24000	7246.4			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	24500	7397.8			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	25000	7549.2			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	25500	7700.6			SMS
1070.27	CR-05-0764	1070.27	50	46.5 : 23.4	23.1	60.5	39.0	0.5	0.34	26000				

TABLE B12.1 CONTINUED (6)

SHAFT/ DRILLHOLE NO.	SAMPLE NO.	DEPTH (in)	ELEVATION (in)	WATER CONTENT (%)	ATTERBERG LIMITS LL PL PI	GRAIN SIZES (in) CLAY SILT SAND	ACTIVITY NORMAL	EFFECTIVE STRESS (lps) RESIDUAL IN SITU	μ' (EACH TEST)	μ' (GROUP) (DEC.)	MATERIAL TESTED
STRATA ELEVATION: 1085 ± to 1090 ± Continued											
SR-46-S707	20	48.34	1087.06	16.0	44.6 23.7 20.9	60 40 0	0.35	1000 303.1	220.0	21.0	SMS
SR-46-S707	18	50.55	1084.43	14.2	43 26 17	49 51 0	0.35	600 325	170	20.4	SMS
SR-46-S707	16	50.55	1084.43	21.8	43 26 17	49 51 0	0.35	1100 400	265	20.0	SMS
SR-46-S707	14	50.55	1084.43	16.5	43 26 17	49 51 0	0.35	1000 560	350	19.3	SMS
CR-47-S750	12	52.29	1085.0		41 21 20	50 40 2	0.4				
CR-47-S751	2	47.95	1089.27		45.0 26.0 19.0	56 43.5 0.5	0.34				
CR-47-S751	3	48.92	1088.36	14.4	49.2 21.9 27.3	63 37 0	0.43	950 367.4	200	21.2	CS
CR-47-S752	10	48.63	1087.40	11.2	46 23 23	52 40 0	0.40	650 305.9	105	19.0	CS
CR-47-S752	11	49.24	1086.79	14.4	47 25 22	59 41 0	0.37	1130 559.2	240	25.9	CS
CR-47-S752	12	50.02	1086.01		39 19.5 19.5	44.5 55 0.5	0.44				
CR-47-S754	11	42.49	1084.92		39.7 19.9 19.4	40 52 0	0.41				
CR-47-S754	13	44.21	1087.60	13.3	39.5 22.0 17.5	40.0 52 0.0		1050 504.1	234	25.6	CS
CR-47-S756	14	46.77	1085.04		41.7 22.3 21.4	51 49 0	0.42				
CR-47-S755	6	44.16	1087.13		45 24 21						
CR-47-S755	7	44.73	1086.56		47.5 23.4 24.1	53 46.5 0.5	0.45				
CR-47-S756	8	32.13	1089.70	17.1	48.5 25.1 24.4	64 35.5 0.5	0.38	650 302.2	150	24.2	SND
CR-47-S756	9	33.0	1088.91		47.4 22.6 24.8	52 47.5 0.5	0.40				
CR-47-S757	7	30.96	1049.92	3.7	31.5 12.0 17.7	25 55 20	0.71				
CR-47-S757	8	32.14	1088.74	3.0	44 17 27	36 61 3	0.75				
CR-47-S757	9	34.31	1046.07	14.3	48.1 20.4 27.7	52 40 0	0.53	950 453.6	200	41.9	CS
CR-47-S758	4	30.14	1086.79	5.2	37.4 18.0 19.4	41 59 0	0.40				
CR-47-S758	5	32.36	1046.57	15.4	47.9 26.7 21.2	61 39 0	0.35	750 472.6	171	33.2	SND
CR-47-S758	5	32.46	1086.47	15.3	52.4 27.1 25.3			950 507.3	200	20.1	SND
CR-47-S758	5	32.43				50 42.0 0.0					CS
CR-47-S758	6	36.05	1042.06	9.4	42.4 23.3 19.5	54 43 3	0.36				
CR-47-S759	9A	21.26	1044.7	15.4	52.7 26.9 25.0	59 41 0	0.44	450 251.3	105.0	29.2	SND
CR-47-S759	9B	21.41	1044.53	16.6	54.3 27.4 26.9	54 46 0	0.50	750 426.4	162	29.6	SND
BT-47-00111	3		1049.04	46.2	51.2 23.9 27.3	47 52.5 0.5	0.50	750 239.1	145	17.7	10.5 ± SMS
BT-47-00111	3		1049.04	20.2	51.2 23.9 27.3	47 52.5 0.5	0.50	1250 316.6	210	14.2	9.9
CR-47-S759	8	19.47	1046.04	18.2	59.4 27.0 32.4	60 31 1	0.40	350 373.6	100	46.9	SND
CR-47-S759	9	21.20	1044.70	15.4				450 251.3	105	29.2	SND
BC-48-S706	6	41.17	1093.36	9.1	31.0 17.5 13.5	5 93 2	2.7	900 549.9	298	33.2	SND

TABLE B12.1 CONTINUED (7)

SAMPLE/ DRILLHOLE NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTENDING LIMITS LL PL PI	GRAIN SIZES (%) CLAY SILT SAND	ACTIVITY	NORMAL	IN SITU SHEAR	EFFECTIVE STRESS (kPa)	RESIDUAL SHEAR	σ'_v IN SITU	σ'_v (BACK TEST) (ORG.)	MATERIAL TESTED
STRATA ELEVATION: 1085 m to 1090 m Continued													
SR-06-5707	43	41.32	15.5	40.0 23.9 24.1	50 40 2	0.40	400	113.4	113.0	15.9			
SR-06-5707	48	41.32	22.0	40.0 23.9 24.1	50 40 2	0.40	700	262.3	220.0	20.5			SMS
SR-06-5707	48	41.32	18.9	40.0 23.9 24.1	50 40 2	0.40	1000	396.0	200.0	21.7			
CR-07-5754	5	32.44		38.1 19.3 18.9	49 51 0	0.39							
CR-07-5754	7	32.95		40 21 19	49 40 3	0.39							
CR-07-5754	8	37.21		40.6 23.4 17.0	49 51 0	0.35							
CR-07-5755	4	31.74	13.1	46.3 20.6 25.7	53 46.5 0.5	0.40	650	499.5	175	37.5			CS
CR-07-5756	4	22.95		40.1 22.6 25.5	47 53 0	0.50							
CR-07-5756	5	23.95			49.1 50.9 0.0								CS
CR-07-5756	7	30.59	0.6	42 19 23	42 50 0	0.55							
CR-07-5757	2	21.92		45 19 27	43 56.5 0.5	0.63							
CR-07-5759	2	22.29		53.7 21.9 31.8	49 51 0	0.65							
CR-07-5759	3	12.67		41.5 16.0 24.7	36 64 0	0.69							
CR-07-5759	4	13.50		42 21 21	35 64 1	0.60							
STRATA ELEVATION: ABOVE 1100 m													
SR-06-5707	50	35.20	15.6	45.7 22.5 23.2	55 44 1	0.42	400	143	100	19.7			SMS
SR-06-5707	50	35.20	31.4	45.7 22.5 23.2	55 44 1	0.42	500	200.4	260	17.0			SMS
SR-06-5707	50	35.26	19.1	41.3 22.3 19.0	44 55.5 0.5	0.43	300	96.7	80	17.9			
SR-06-5707	50	35.26	15.1	41.3 22.3 19.0	44 55.5 0.5	0.43	600	260.2	200	22.4		16.4	SMS
SR-06-5707	50	35.26	31.1	41.3 22.3 19.0	44 55.5 0.5	0.43	650	271.5	105	22.7			
RC-06-5706	4	29.6	19.2	40.5 21.3 26.8	60 40 0	0.45	600	145.2	122	13.6			SMD
RC-06-5711	5	36.53		39.2 19.9 19.3	44 56 0	0.40	900	1216.1	352	53.4			CS
RC-06-5712	6	15.09	13.0	42.5 14.9 23.6	44 56 0	0.54	735	307.3	275	28.7			SMD
SR-06-5707	60	30.63	10.2	45.7 22.0 23.7	62 30 0	0.30	300	64.1	57	12.1			SMS
SR-06-5707	60	30.63	16.1	45.7 22.0 23.7	62 30 0	0.30	600	141.5	115	13.3			
SR-06-5707	60	30.63	14.4	45.7 22.0 23.7	62 30 0	0.30	900	242.6	100	15.1		11.0	
SR-06-5707	60	30.63	17.3	45.9 24.2 21.7	53 47 0	0.41	300	42.2	40	15.3			
SR-06-5707	60	30.63	13.8	45.9 24.2 21.7	53 47 0	0.41	600	192.3	140	17.8		13.7	
SR-06-5707	60	30.63	13.5	45.9 24.2 21.7	53 47 0	0.41	900	202.0	220	17.4			SMS

TABLE H12.1 CONTINUED (8)

SHAFT/ DRILLHOLE NO.	SAMPLE NO.	DEPTH (ft)	ELEVATION (ft)	WATER CONTENT (%)	ATTENING LIMITS LL PL PI	GRAIN SIZES (%) CLAY SILT SAND	ACTIVITY	NORMAL	EFFECTIVE STRESS (kPa)	RESIDUAL SHEAR	β' IN SITU	β_c' (BACK TEST) (DEC.)	β_c' (GROUP) (DEC.)	MATERIAL TESTED
STRATA ELEVATION: ABOVE 1100 = Continued														
SR-46-S707	70	30.70	1104.68	18.3	69.2 26.0 23.2 57	42.5 0.5 0.41		300	95.7	75.0	17.7	14.0		
SR-46-S707	70	30.70	1104.68	17.5	69.2 26.0 23.2 57	42.5 0.5 0.41		600	160.7	134	15.0	12.6	13.0	
SR-46-S707	70	30.70	1104.68	15.3	69.2 26.0 23.2 57	42.5 0.5 0.41		900	252.5	252.5	15.7	15.7		
SR-46-S707	80	29.75	1105.63	16.5	64.3 24.4 19.9 56	44 0 0.36		200	114.2	93	29.3	24.9		
SR-46-S707	80	29.75	1105.63	15.5	64.3 24.4 19.9 56	44 0 0.36		500	202.6	165	22.1	18.8	18.8	SMS
SR-46-S707	80	29.75	1105.63	12.6	64.3 24.4 19.9 56	44 0 0.36		1000	346.9	297	24.6	20.4		
SR-46-S707	90	28.27	1107.11	-	30 23 15 60	60 0 0.38		800	-	250		17.4		
BC-46-S706	3	26.75	1107.78	15.3	63.1 20.9 22.2 56	66 0 0.40		300	257.3	66	40.6	15.6		SMD
SR-46-S707	100	21.15	1114.23	22	66 21 25 30	61 1 0.66		200	97.6	13	26.0	22.5		
SR-46-S707	100	21.15	1114.23	21.2	66 21 25 30	61 1 0.66		500	191.2	90	20.9	18.2		SMS
SR-46-S707	100	21.15	1114.23	25.6	66 21 25 30	61 1 0.66		1000	264.7	155	18.3	11.0		
CR-45-T318	2	11.55	1117.7	16.2	- - - -	- - - -		437	396.3	186.0	25.6	12.7		SMD
CR-47-S750	6	20.49	1112.40	12.2	45.0 23.3 21.7 59	40.5 0.5 0.37		350	321.6	118.0	32.3	18.6		SMD
CR-47-S750	8	30.94	1106.35	14.0	51.0 25.1 25.9 60	40 0 0.43		650	312.6	142.0	25.7	12.3		SMD
CR-47-S750	1	18.45	1120.44	24.3	46.6 22.6 23.0 35	65 0 0.46		350	156.5	60	24.4	14.1		SMD
CR-47-S750	2	16.7	1120.44	11.2	40.5 24.2 24.3 39.0	61.0 0.0 0.62		550	306.1	141	28.9	14.4		SMD
CR-47-S750	3	18.9	1118.39	-	56.0 23.8 23.2 61	39 0 0.53		-	-	-	-	-	-	CS
CR-47-S750	4	19.47	1117.42	14.0	45.0 20.5 25.3 61	46 56 0 0.58		350	318.7	121	42.3	19.1		SMD
CR-47-S750	5	22.39	1114.90	15.9	49.0 25.0 24.0 65	34.5 0.5 0.37		650	431.3	140	33.6	12.2		SMD
CR-47-S750	5	22.36	1114.93	14.2	49.0 25.0 24.0 65	34.5 0.5 0.37		950	495	236	27.5	13.4		SMD
CR-47-S750	6	24.90	1112.39	12.2	45.0 23.3 21.7 59	40.5 0.5 0.37		350	221.6	118.0	32.3	18.6		SMD
CR-47-S750	7	28.3	1108.99	-	38.2 18.7 19.3 61	51.5 1.5 0.41		650	312.6	142.0	25.7	12.3		SMD
CR-47-S750	8	30.94	1106.35	14.0	51.0 25.1 25.9 60	40 0 0.43		650	312.6	142.0	25.7	12.3		SMD
CR-47-S750	8	30.91	1106.38	8.2	65.5 21.4 24.1 51.3	40.9 0.0 0.47		650	346.6	143.0	30.7	12.4		SMD
CR-47-S750	8	30.96	1106.33	14.0	43.9 17.4 26.3 65	55 0 0.59		-	-	-	-	-	-	SMD
CR-47-S750	9	33.66	1103.63	-	46 23 23 54	46 0 0.43		-	-	-	-	-	-	SMD
CR-47-S750	9	33.74	1103.55	-	47 22 25 40	51.5 0.5 0.52		-	-	-	-	-	-	CS
CR-47-S752	1	16.56	1119.47	19.2	51.1 21.8 24.3 49	50.5 0.5 0.6		350	178.8	61	27.1	9.9		CS
CR-47-S752	1	16.61	1119.42	17.0	51.1 21.8 24.3 49	50.5 0.5 0.6		550	324.4	101	30.5	14.4		CS
CR-47-S752	1	16.63	1119.40	17.2	51.1 21.8 24.3 49	50.5 0.5 0.6		750	409.4	105	33.1	11.0		CS
CR-47-S752	2	18.31	1117.72	13.9	47.3 21.2 26.1	-		450	217.5	80	25.8	10.1		SMD
CR-47-S752	2	18.31	1117.7	-	-	42.6 57.4 78		-	-	-	-	-	-	CS
CR-47-S752	3	18.76	1117.35	-	41.4 18.9 22.9 34.4	65.6 0.0 0.67		-	-	-	-	-	-	CS
CR-47-S752	4	23.48	1112.55	18.2	56.2 23.0 31.2 60	40 0 0.52		350	209.8	63	35.5	10.2		CS
CR-47-S752	4	23.51	1112.52	16.3	56.2 23.0 31.2 60	40 0 0.52		550	446.6	155	40.3	15.7		CS
CR-47-S752	4	23.54	1112.49	16.7	56.2 23.0 31.2 60	40 0 0.52		750	535.3	160	35.5	12.0		CS

TABLE 112.1 CONTINUED (9)

SHAFT/ DRILLHOLE NO.:	SAMPLE: NO.:	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	LL	PL	PI	CLAY	SILT	SAND	ACTIVITY	ROLL	IN SITU SHEAR	EFFECTIVE STRESS (kPa)	RESIDUAL: SHEAR	β_c (kN/m ²) (ORC.)	TEST: (ORC.)	MATERIAL TESTED
STRATA ELEVATION: ABOVE 1100 m continued																		
CR-07-3752	6	29.11	1106.92		47.4	22.9	24.5	53	47	0	0.46							CS
CR-07-3752	6	29.19	1106.84		41.3	20.2	21.1	49	50.5	0.5	0.43							CS
CR-07-3752	7	31.46	1104.87	6.3	41.3	21.5	19.8	48.5	51.5	0.0	0.41	450		300.6	350	25.4	13.7	SHD
CR-07-3752	8	35.05	1100.90		46.6	21.7	24.9	53	46.5	0.5	0.46							CS
CR-07-3752	8	35.36	1100.67		38.2	15.9	12.4	27	72	1	0.46							CS
CR-07-3753	2	21.48	1108.72	17.5	52	19.7	32.3	49	51	0	0.66	450	300.5		126	33.7	15.6	CS
CR-07-3753	3	23.44	1107.76	16.5	44	22.1	21.9	41	59	0	0.53	750	365.0		220	26.0	16.3	SHD
CR-07-3753	6	28.43	1101.37	15.5	37.4	19.4	17.9	44	56	0	0.41	450	227.0		115	26.0	14.3	SHD
CR-07-3754	2	27.29	1104.52	7.4	39.9*	20.1	13.8	28.5*	71.5	0.0	0.48	750	307		210	27.3	15.6	SHD
CR-07-3754	2	27.3	1104.57		46.0	19.3	26.7	42.2	57.0	0.0	0.63							CS
CR-07-3754	3	27.45	1103.96		45.7	17.9	27.8	51	49	0	0.55							
CR-07-3755	1	21.33	1110.66		50.4	23.6	26.8	49	51	0	0.55							
CR-07-3756	20	19.44	1102.07	10.3	54.6	27.5	27.1	57.5	42.5	0	0.47							
CR-07-3756	20	20.49	1101.02	12.2	53.5	27.6	25.9	57	43	0	0.45							
SR-06-3707	100	21.5	1116.23	16.3	46	21	25	38	61	1	0.66	1350	647.1		545	25.6	22	SHS
UPSTREAM DIVERSION TUNNEL PORTAL - SEAM 2																		
SR-0-190	SR2-1	1	1001.69	9.9								450	296		120	33.3	15.4	SHS
SR-0-190	SR2-1	1	1001.69	4.7	27.4*	16.0	11.0	16.0*	82.1	1.9	0.49							CS-B
SR-0-190	SR2-1	1	1001.69		35.9	14.9	17.0											CS-B
SR-0-190	SR2-1	1	1001.69	9.9	36.7*	20.7	18.0	20*	72	0	0.64							SHS
SR-0-190	SR2-1	1	1001.69		45.1	22.9	22.2	36.0	64.0	0.0	0.62							SHS
SR-0-190	SR2-1	1	1001.69		33.0	18.2	14.8											CS-L
SR-0-190	SR2-1	1	1001.69	6.5	27.5*	14.0	9.5	14.0*	80.0	2.0	0.53							CS-L
SR-0-190	SR2-1	1	1001.69	4.7	27.4*	17.2	10.1	13*	86	1.0	0.70							CS-B
SR-0-190	SR2-1	1	1001.69		36.4	20	16.4											CS-B
SR-0-190	SR2-1	1	1001.69	10.2	37.2*	20.2	17.0	21*	79	98	0.81							SHS
SR-0-190	SR2-1	1	1001.69		27.5	20.4	17.1											CS-L
SR-0-190	SR2-1	1	1001.69	5.0	30.4*	10.4	12.0	22.5*	74.5	0.0	0.53							CS-L
SR-0-190	SR2-2	1	1001.00	6.2	36.4*	21.0	15.0					750	220		152	16.6	11.5	SHS
SR-0-190	SR2-2	1	1001.00		27.0*	17.0	10.0	11.0*	86.2	2.6	0.91							CS-B
SR-0-190	SR2-2	1	1001.00		38.6	17.6	21.0	29	71	0.0	0.72							CS-B
SR-0-190	SR2-2	1	1001.00		52.7	25.7	27.0	49	50	1.0	0.55							CS-L
SR-0-190	SR2-2	1	1001.00					26.0*	74.0	0.0								CS-L
SR-0-190	SR2-2	1	1001.00		41.1	22.1	18.7											

TABLE B12.1 CONTINUED (10)

SHAFT/ DRILLHOLE NO.	SAMPLE/ NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTENBERG LIMITS			GRAIN SIZES (N)			ACTIVITY	EFFECTIVE STRESS (kPa)		RESIDUAL		β' IN SITU	β' (EACH TEST)	β' (GROUP)	MATERIAL TESTED
					LL	PL	PI	CLAY	SILT	SAND		NORMAL	IN SITU	SHEAR					
UPSTREAM DIVERSION TUNNEL PORTAL - SEAM 2 Continued																			
57A-862	572-4-1		1002.81	12.5	44	22	22	52.0	47.0	0.2	0.42	750	378	145	26.7	10.9			SMS
57A-862	572-4-1		1002.81	12.5	37*	23	14	29.5*	70.0	0.5	0.40								SMS
57A-862	572-4-1		1002.81	5.2	26*	19	7	15.0*	85.0	0.0	0.47								CS-0
57A-862	572-4-1		1002.81	5.2	32.0	19.0	13.0	26.0	74.0	0.0	0.50								CS-0
57A-862	572-4-1		1002.81	6.2	25*	19	6	16.0*	84.0	0.0	0.38								CS-0
57A-862	572-4-1		1002.81	6.2	36	19	17	29.9	70.0	0.1	0.57								CS-0
57A-862	572-4-1		1002.81	12.7	37.0*	24.0	13.0	29.5*	70.0	0.5	0.40	350	203	70	30.1	11.3			SMS
57A-862	572-4-1		1002.81		49	24	25	51	49	0.0	0.49								SMS
57A-862	572-4-1		1002.81	5.5	35.0	18.0	17.0	26.0	74.0	0.0	0.65								CS-0
57A-862	572-4-1		1002.81	5.5	26.0*	19.0	7.0	14.5*	85.0	0.5	0.48								CS-0
57A-862	572-4-1		1002.81	7.3	34.0	18.0	16.0	29.1	70.5	0.0	0.55								CS-0
57A-862	572-4-1		1002.81	7.3	25.0*	19.0	6.0	9.9*	90.1	0.0	0.61								CS-0
57A-862	572		1002.81		35.6	19.1	16.5	27.0	53.0	0.0	0.36								SMS
57A-862	572-4-1		1002.81		50.0	24.0	26.0	48.9	51.1	0.0	0.53								SMS
57A-862	572-4-1		1002.81		39	20	18.0	35	65	0.0	0.56								CS-0
57A-862	572-4-1		1002.81		20.0*	20.0	0.0	10.9*	40.0	1.1	0.73								CS-0
57A-862	572-4-1		1002.81		35	22	13	26.7	73.0	0.3	0.49								CS-0
57A-8-102	572		1003.07		41.1	23.0	18.1	24.0	76.0	0.0	0.75								SMS
57A-8-121	572-2-1		1003.07		31.5*	17.4	13.7	20.0*	77.0	2.2	0.69								CS-0
57A-8-121	572-2-1		1003.07		29.0*	19.5	9.9	13.5*	85	1.5	0.73								CS-0
57A-8-121	572-2-1		1003.07		35.5*	19.1	16.4	18.0*	81.1	0.5	0.91								SMS
57A-8-121	572		1003.07		45.9	24.5	21.4	40.0	60.0	0.0	0.54								SMS
57A-8-121	572-3-1		1003.07	6.0	26.9*	18.7	8.2	10*	40.9	1.1	0.82								CS-0
57A-8-121	572-3-1		1003.07	14.0	36.0*	19.4	15.0	21*	70.1	0.9	0.71	750	400	203	30.6	21.3			SMS
57A-8-121	572-3-1		1003.07		20.3*	18.1	10.6												CS-0
57A-8-121	572-2-1		1003.07		40.5	19.3	21.2												CS-0
57A-8-121	572-2-1		1003.07		40.9	21.2	23.7												SMS
57A-8-121	572-3-1		1003.07		45.4	24.0	21.6	36.0	63.5	0.5	0.40								SMS
57A-8-121	572-2-1		1003.07		30.3	19.0	19.7												CS-0
57A-8-121	572-3-1		1003.07	6.0				25.5	74	0.5									CS-0
57A-8-121	572-3-1		1003.07		39.4	21.9	17.5												CS-0
57A-8-139A	572-2-1		1003.2	9.9	40	24	20	45	55	0.0	0.53	650	199	160	15.4	13.0			SMS
57A-8-139A	572-3-1		1003.2	6.9	36	17	19	30	70	0.0	0.63								CS-0
57A-8-139A	572-3-1		1003.2	6.9	20*	20	8	10*	48.5	1.5	0.40								CS-0

TABLE B12.1 CONTINUED (11)

SHAFT/ BRIGGS NO.	SAMPLE NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTERBURG LIMITS LL PL PI	CLAY SILT CLAY SILT	SAND SAND	ACTIVITY	NORMAL	IN SITU SEAR	RESIDUAL SEAR	ρ' IN SITU (kPa)	ρ'_c (kPa)	ρ'_c (kPa)	MATERIAL TESTED
UPSTREAM DIVERSION TUNNEL PORTAL - SCAN 2 - Continued															
STA-0-139A	SF2-3 1		1003.2	12.0	53 26 27	52 40 0.0	0.52		350	119	87	18.8	14.0		SMS
STA-0-139A	SF2-3 1		1003.2	5.5	36 20 16	26 72 0.0	0.57								CS-L
STA-0-139A	SF2-3 1		1003.2	5.5	27* 20 7	9* 90.4 0.6	0.78								CS-L
STA-0-139A	SF2-3 2		1003.2	4.8	36 20 16	31 69 0.0	0.52								CS-L
STA-0-139A	SF2-3 2		1003.2	4.4		11* 80 1.0									CS-L
STA-0-139A	SF2-3 2		1003.2	11.2	51 25 26	52 48.0 0.0	0.50		850	220	137.5	14.5	10.8		SMS
STA-0-139A	SF2-3 2		1003.2	11.2	26* 18 8										SMS
STA-0-139A	SF2-3 2		1003.2	6.4	37 19 18	29 71 0.0	0.62								CS-L
STA-0-139A	SF2-3 2		1003.2	6.4	26* 19 7.0	4* 91.1 0.5	0.81								CS-L
STA-0-139A	SF2-3 3		1003.2	11.2	47 21 26	42 50 0.0	0.62		950	262	224	16.5	13.3		SMS
STA-0-139A	SF2-3 3		1003.2	5.4	32 19 13										CS-L
STA-0-139A	SF2-3 3		1003.2	5.4	26* 18 8	16* 84.0 1.2	0.57								CS-L
STA-0-139	SF2-4 1		1003.2	11.6	38.0* 22.0 16.0	34.6* 65.0 0.4	0.46								SMS
STA-0-139	SF2-4 1		1003.2	11.6	55.0 26.0 29.0	52.0 40.0 0.0	0.56								SMS
STA-0-139	SF2-4 1		1003.2	5.0	37.0* 20.4 7.0	13.9* 85.0 1.1	0.50								CS-L
STA-0-139	SF2-4 1		1003.2	5.0	36 19 17	26.5 73.5 0.0	0.60								CS-L
STA-0-139	SF2-4 1		1003.2	6.4	39.0 20.0 19.0	32.0 64.0 0.0	0.59								CS-L
STA-0-139	SF2-4 1		1003.2	6.4	28.0* 28.0 8.0	15.5* 84.5 0.0	0.52								CS-L
STA-0-139	SF2-4 1		1003.2	5.4	26.0* 26.0 6.0	14.5* 84.0 1.5	0.41								CS-L
STA-0-139	SF2-4 1		1003.2	5.4	36 19 17	28.0 70.0 0.2	0.57								SMS
STA-0-139	SF2-4 1		1003.2	10.6	37.0* 23.0 14.0	27.4* 72.0 0.6	0.51								CS-L
STA-0-139	SF2-4 1		1003.2	6.7	29.0* 21 8	17.0* 83.0 0.0	0.47								SMS
STA-0-139	SF2-4 1		1003.2	10.6	51 24 27	53.0 47.0 0.0	0.51								SMS
STA-0-139	SF2-4 1		1003.2			34.5* 61.5 0.0									SMS
STA-0-139	SF2-4 1		1003.2		34 18 16	27.4 72.0 0.2	0.56								CS-L
STA-0-139	SF2-4 1		1003.2		27* 20 17	8.0* 92.0 0.0	0.80								CS-L
STA-0-139	SF2-4 1		1003.2		50 23 17	47.2 52.7 0.1	0.57								SMS
STA-0-139	SF2-4 1		1003.2		41 21 20	34.3 65.0 0.0	0.59								CS-L
STA-0-139	SF2-4 1		1003.2		39.0* 23.0 16.0										SMS
STA-0-139	SF2-4 1		1003.2	11.6	55.0 26.0 29.0				750	250	140	19.0	10.6		SMS
STA-0-139	SF2-4 1		1003.2	11.6	57.2 30.4 30.4	47.0 53.0 0.0	0.65								SMS
STA-0-139	SF2-4 1		1003.2		30* 21 9	14.0* 84 1.4									CS-L
STA-0-139	SF2-4 1		1003.2		37 21 16	22 78 0									CS-L
UPSTREAM DIVERSION TUNNEL PORTAL - SCAN 3															
STA-0-19	SF2-3 1		1001.56		34.5* 20.1 14.4	34.0* 63.2 2.0	0.42								CS-L
STA-0-19	SF2-3 1		1001.56		46.2 27.3 18.9										CS-L
STA-0-19	SF2-3 1		1001.56	8.3	42.6* 22.7 19.9	37.5* 56.2 6.3	0.53		750	155	155	11.7	11.7		SMS
STA-0-19	SF2-3 1		1001.56	8.3	36.4 31.0 25.8	50 42 0.0	0.44								SMS
STA-0-19	SF2-3 1		1001.56		38.4* 22.1 17.3	36.0* 54.8 9.2	0.40								CS-L
STA-0-19	SF2-3 1		1001.56		54.4 29.7 24.7	63 47 0.0	0.39								CS-L

TABLE 912.1 CONTINUED (12)

SHAFT/ DRILLHOLE NO.	SAMPLE NO.	DEPTH (ft)	ELEVATION (ft)	WATER CONTENT (%)	ATTENDING LIMITS				GRAIN SIZES (%)			ACTIVITY	NORMAL	IN SITU SHEAR	σ' IN SITU	μ'	μ'_c (GROUP) (DESC.)	MATERIAL TESTED
					LL	PL	PI	CLAY	SILT	SAND	NORMAL							
UPSTREAM DIVERSION TUNNEL PORTAL - SEAM } Continued																		
57A-0-62	573-2	1	1002.28	14.1	62.0	20.0	22.0	41.0	58.0	0.0	0.54	750	516	200	35.5	20.5		SMS
57A-0-62	573		1002.28		52.0	31.1	21.7	41.0	57.0	0.0	0.51							SMS
57A-0-62	573-2	1	1002.28		35.0	19.0	16.0	27.0	73.0	0.0	0.59							CS-0
57A-0-62	573-2	1	1002.28		25.0	20.0	5.0	10.1	89.9	0.0	0.50							CS-0
57A-0-62	573-2	1	1002.28		35.0	20.0	19.0	41.5	58.0	0.5	0.46							CS-0
57A-0-62	573-2	2	1002.28		31.0	19.0	12.0	14.0	86.0	0.0	0.46							CS-0
57A-0-62	573-2	2	1002.28		36.0	19.0	15.0	30.0	69.0	0.2	0.45							CS-0
57A-0-62	573-2	2	1002.28		25.0	17.0	6.0	9.9	90.1	0.0	0.41							CS-0
57A-0-62	573-2	2	1002.28	12.3	43.0	17.0	26.0	41	59	0.0	0.63	650	506	200	30.0	18.2		SMS
57A-0-62	573-2	2	1002.28		35.0	20.0	19.0	37.9	60.0	1.3	0.50							CS-0
57A-0-62	573-2	2	1002.28		27.0	15.0	8.0	18.0	77.0	5.0	0.44							CS-0
57A-0-62	573-2	3	1002.28		35.0	18.0	17.0	29.0	71.0	0.0	0.59							CS-0
57A-0-62	573-2	3	1002.28		25.0	15.0	6.0	8.0	95.0	7.0	0.35							CS-0
57A-0-62	573-2	3	1002.28	12.3	45	22	23	40	60.0	0.0	0.58	950	602	335	32.4	18.9		SMS
57A-0-62	573-2	3	1002.28		40.0	21.0	19.0	39.5	59.0	1.5	0.48							CS-0
57A-0-62	573-2	3	1002.28		25.0	17.0	6.0	17.0	83.0	0.0	0.53							CS-0
57A-0-62	573-2	4	1002.28		31.0	17.0	14.0	26.5	73.0	0.5	0.57							CS-0
57A-0-62	573-2	4	1002.28		26.0	20.0	6.0	6.0	92.0	0.0	0.75	650	426	277	33.2	23.1		CS-0
57A-0-62	573-2	4	1002.28	10.3	30.0	19.0	19.0	34.0	66.0	0.0	0.56							SMS
57A-0-62	573-2	4	1002.28	10.7	33.0	21.0	12.0	22.0	77.0	1.0	0.55							SMS
57A-0-62	573-2	4	1002.28		35.0	20.0	19.0	37.4	61.0	1.6	0.51							CS-0
57A-0-62	573-2	4	1002.28		29.0	20.0	9.0	14.7	80.0	5.3	0.61							CS-0
57A-0-102	573-0	1	1002.6	13.0	43	21.0	22.0	31.0	64.3	0.7	0.71	1000	600	430	31.0	23.3		SMS
57A-0-102	573-0	1	1002.6	13.0	34.0	21.0	13.0	20.0	74.9	1.1	0.65							SMS
57A-0-102	573-0	1	1002.6									750	515	300	34.5	21.0		SMS
57A-0-102	573-0	1	1002.6	13.0								1250	720	425	29.9	18.0		SMS
57A-0-102	573-0	1	1002.6	12.2	40	22.0	25.5	66.5	0.0			350	276	127	30.3	19.9		SMS
57A-0-102	573-0	1	1002.6	6.5	40.0	22.0	11.0	32.0	64.0	0.0	0.56							CS-0
57A-0-102	573-0	1	1002.6	4.5	32.0	20.0	12.0	18.0	82.0	0.0	0.67							CS-0
57A-0-102	573-0	1	1002.6	6.0	38.0	19.0	19.0	29.5	69.7	0.4	0.64							CS-0
57A-0-102	573-0	1	1002.6	6.0	29.0	20.0	9.0	17.0	81.4	1.6	0.53							CS-0
57A-0-102	573-0	1	1002.6	5.8	38.0	21.0	17.0	29.0	71.0	0.0	0.59							CS-0
57A-0-102	573-0	1	1002.6	5.0	27.0	20.0	7.0	17.0	83.0	0.0	0.41							CS-0
57A-0-102	573-0	1	1002.6	6.0	41.0	21.0	22.0	36.9	62.0	1.3	0.60							CS-0
57A-0-102	573-0	1	1002.6	6.0	31.0	20.0	21.0	22.0	75.6	2.4	0.50							CS-0

TABLE 112.1 CONTINUED (13)

[illegible]

TABLE B12.1 CONTINUED (14)

SHAFT/ DRILLHOLE NO.	SAMPLE NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATYRING LIMITS LL PL PI	GRAIN SIZES (N) CLAY SILT SAND	ACTIVITY	NORMAL	EFFECTIVE STRESS (kPa)	RESIDUAL SHEAR	IN SITU SHEAR	β_c (EACH TEST)	β_c (GROUP) (DEC.)	MATERIAL TESTED
UPSTREAM DIVERSION TUNNEL PORTAL - SEAM 3 Continued														
57A-B-121	573-2	1	1082.6			55.0 43.6 3.4								CS-L
57A-B-121	573-2	12	1082.6	9.1	54.0 25.5 29.3	60.0 40.0 0.0	0.49							CS-L
57A-B-121	573-2	12	1082.6	9.1	38.9 22.4 16.5	32.0 55.2 12.8	0.52							CS-L
57A-B-121	573-2	12	1082.6	7.5	40.7 20.2 20.5	41.0 59.0 0.0	0.50							CS-B
57A-B-121	573-2	12	1082.6	7.5		23.0 70.7 6.3								CS-B
57A-B-121	573-2	12	1082.6	16.7	41.3 22.4 18.8	40 59.0 1.0	0.47							SMS
57A-B-121	573-2	12	1082.6	16.7	50.2 21.5 20.7	55.5 40.5 0.0	0.48							SMS
57A-B-121	573-2	13	1082.6			34.0 66.0 0.0								SMS
57A-B-121	573-3	1	1082.6		38.6 21.2 17.4	29.5 65.9 4.6	0.59							CS-L
57A-B-121	573-3	1	1082.6		50.6 23.0 27.6	36 43.5 0.5	0.49							CS-L
57A-B-121	573-3	1	1082.6		43.6 22.0 20.8	34.0 63.0 3.0	0.61	350	157	120	24.2	19.9		SMS
57A-B-121	573-3	1	1082.6		53.6 26.8 26.9									SMS
57A-B-121	573-3	1	1082.6		30.4 17.9 12.9	22.0 75.1 2.4	0.59							CS-B
57A-B-121	573-3	1	1082.6		48.6 22.0 26.6	39 60.5 0.5	0.60							CS-B
57A-B-121	573-3	1	1082.6		36.7 22.6 14.1									CS-L
57A-B-121	573-3	1	1082.6			32.5 62.2 5.3								CS-L
57A-B-121	573-4	1	1082.3	6.2	41.3 19.3 22.0	40.0 52.0 0.0	0.46							CS-B
57A-B-121	573-4	1	1082.3	6.2	31.9 19.3 12.6	24.0 69.9 21.	0.45							CS-B
57A-B-121	573-4	1	1082.3	15.9	54.0 24.4 29.6	41.5 38.5 0.0	0.40	550	150	100	15.3	11.1		SMS
57A-B-121	573-4	1	1082.3	15.9	37.3 23.1 14.2	34.5 59.6 5.9	0.41							SMS
57A-B-121	573-4	1	1082.3	7.9	47.3 24.6 22.7	52.0 48.0 0.0	0.40							CS-L
57A-B-121	573-4	1	1082.3	7.9	33.6 20.2 13.4	38.0 65.1 6.9	0.45							CS-L
57A-B-121	573-4	1	1082.3	5.4	43.9 20.9 23.0	44.0 54.5 1.5	0.52							CS-B
57A-B-121	573-4	1	1082.3	5.8	30.2 18.4 11.8	26.0 72.0 1.2	0.45							CS-B
57A-B-121	573-4	1	1082.3	6.1	48.6 23.6 25.0	45.0 55.0 0.0	0.56	950	300	240	17.5	16.4		SMS
57A-B-121	573-4	1	1082.3	6.1	35.0 20.5 14.5	29.5 69.1 1.4	0.49							SMS
57A-B-121	573-4	1	1082.3	6.3	47.5 24.0 23.5	56.0 43.3 0.7	0.42							CS-L
57A-B-121	573-4	1	1082.3	6.3	31.4 20.6 11.0									CS-L
57A-B-121	573-4	1	1082.3		33.3 20.0 13.3									CS-B
57A-B-139	573				49.0 22.9 26.1	30.0 62.0 0.0								SMS
57A-B-139A	573-1	1	1082.52	9.2	40.0 20	27.6 69.6 0.0	0.73	450	250	195	29.1	23.4		SMS (H1600)
57A-B-139A	573-1	1	1082.52	9.2	34.0 20	34 22.0 76.4 1.2	0.61							SMS
57A-B-139A	573-1	1	1082.52		27 19	15.3 40.0 0.7	0.52							CS-B
57A-B-139A	573-1	1	1082.52		36 10	14.0 31 69 0.0	0.50							CS-B
57A-B-139A	573-1	2	1082.52	6.4	37.0 19.0 18.0	35.0 75.0 0.0	0.72							CS-B
57A-B-139A	573-1	2	1082.52	6.8	27.4 19	7.7 50.0 0.3	0.43	400	190	145	35.4	19.9		SMS (H1600)
57A-B-139A	573-1	2	1082.52	11.1	41 21	37.0 62.9 0.1	0.54							CS-L
57A-B-139A	573-1	2	1082.52	11.1	35 20	35 20.0 78.0 1.2	0.72							SMS
57A-B-139A	573-1	2	1082.52		43 22	23 49 11 0.0	0.47							CS-L
57A-B-139A	573-1	1	1082.52		42 20	23 37 63 0.0	0.60							SMS
57A-B-139A	573-1	1	1082.52		34 20	14 26 73.3 0.3	0.50							SMS

TABLE B.12.1 CONTINUED (19)

SHAFT/ BOREHOLE NO. :	SAMPLES NO. :	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTRACTIVE LIMITS				CLIN SIZES (%)				ACTIVITY	EFFECTIVE STRESS (kPa)		RESIDUAL SHEAR	P _r IN SITU	P _r (kPa)	GROUP (ORC.)	MATERIAL TESTED
					LL	PL	FI	CLAY	SILT	SAND	NORMAL	IN SITU								
UPSTREAM DIVERSION TUNNEL PORTAL - SEAM 3 continued																				
STA-0-139A	SF3-2 1		1002.47	5.3	35	18	17	10.8%	69.2	0.0	0.55									CS-0
STA-0-139A	SF3-2 1		1002.47	5.3	27*	20	7	11.3%	87	1.7	0.62									CS-0
STA-0-139A	SF3-2 1		1002.47	9.5	43	22	21	40	60	0.0	0.53	350	155		120	23.9		18.9		SMS
STA-0-139A	SF3-2 1		1002.47	9.5	36*	20	14													SMS
STA-0-139A	SF3-2 1		1002.47		23*	20	13	27*	66.5	6.5	0.63									CS-0
STA-0-139A	SF3-2 1		1002.47		44	23	22	41	59	0.0	0.54									CS-0
STA-0-139A	SF3-2 2		1002.47		27*	20	7	11.1%	88.0	0.9	0.63									CS-0
STA-0-139A	SF3-2 2		1002.47		38	19	19	32.0	67.9	0.1	0.59									CS-0
STA-0-139A	SF3-2 2		1002.47	11.1	43	21	22	38	62	0.0	0.58	450	200		167	26.0		20.4		SMS
STA-0-139A	SF3-2 2		1002.47	11.1	35*	20	15	36*	73.2	0.8	0.42									SMS
STA-0-139A	SF3-2 2		1002.47		41	21	20	30.5	69.1	0.4	0.66									CS-0
STA-0-139A	SF3-2 2		1002.47		26*	20	14													CS-0
STA-0-139A	SF3-2 3		1002.47		33	18	15	26.8	70.1	0.1	0.50									CS-0
STA-0-139A	SF3-2 3		1002.47		25*	17	8	9.5*	88.0	2.1	0.41									CS-0
STA-0-139A	SF3-2 3		1002.47	9.6	44	21	23	40	60	0.0	0.50	350	191		120	26.6		18.9		SMS
STA-0-139A	SF3-2 3		1002.47	9.6				27*	71.3	1.7										SMS
STA-0-139A	SF3-2 3		1002.47		46	21	25	39	61	0.0										CS-0
STA-0-139A	SF3-2 4		1002.47					12.9%	86.0	1.1										CS-0
STA-0-139A	SF3-2 4		1002.47		35	19	16	32.0	67.8	0.2	0.50									CS-0
STA-0-139A	SF3-2 4		1002.47	10.3	42	21	21	37	63	0.0	0.57	375	179		131	25.5		19.3		SMS (H1050)
STA-0-139A	SF3-2 4		1002.47	10.3				29*	71	0.0										SMS
STA-0-139A	SF3-2 4		1002.47		31*	21	10													CS-0
STA-0-139A	SF3-2 4		1002.47		44	21	23	39	61	0.0	0.59									CS-0
STA-0-139A	SF3-2 5		1002.47		34	19	15													SMS
STA-0-139A	SF3-3 1		1002.5	8.4	43.0	20.0	22.0	34.5	65.5	0.0	0.41									CS-0
STA-0-139A	SF3-3 1		1002.5	8.4	34.0*	22.0	12.0	39.0*	68.9	2.1	0.41									CS-0
STA-0-139A	SF3-3 1		1002.5		38.0	20.0	25	31.0	69.9	0.0	0.50									CS-0
STA-0-139A	SF3-3 1		1002.5	5.8	36.0*	19.0	7.0	15.0*	64.4	0.6	0.47									CS-0
STA-0-139A	SF3-3 1		1002.5	10.6	43.0	21.0	22.0	40.0	59.9	0.1	0.55	750	456		260	31.2		19.1		SMS
STA-0-139A	SF3-3 1		1002.5		35.0*	21.0	14.0	38.0	70.0	0.0	0.47									SMS

TABLE B.12.1 CONTINUED (16)

SHAFT/ DRILLHOLE NO. 1	SAMPLE/ NO.	DEPTH (m)	ELEVATION (m)	WATER CONTENT (%)	ATTENBERG LIMITS			GRAIN SIZES (%)			EFFECTIVE STRESS (kPa)			β_r (EACH TEST)	β_r (GROUP) (DEC.)	MATERIAL TESTED	
					LL	PL	PI	CLAY	SILT	SAND	ACTIVITY	NORMAL	IN SITU				SEAL
UPSTREAM DIVERSION TUNNEL PORTAL - SEAM 3 continued																	
STA-B-139A	SP3-3 1 2		1002.5	10.7	42.0	21.0	21.0	37.6	61.0	1.4	0.56	950	607	312	32.6	18.3	SBS
STA-B-139A	SP3-3 1 2		1002.5	10.7	36.0	21.0	15.0	27.0	73.0	0.0	0.56						SBS
STA-B-139A	SP3-3 1 2		1002.5		34.0	20.0	14.0	29.0	71.0	0.0	0.40						CS-B
STA-B-139A	SP3-3 1 2		1002.5		36.0	19.0	7.0	14.0	86.0	0.0	0.50						CS-B
STA-B-139A	SP3-3 1 2		1002.5		44.0	21.0	23.0	40.0	59.4	0.0	0.50						CS-B
STA-B-139A	SP3-3 1 2		1002.5		32.0	20.0	12.0	24.0	76.0	0.0	0.50						CS-B
STA-B-139A	SP3-3 1 3		1002.5	5.3	41.0	21.0	20.0	20.0	71.2	0.0	0.40						CS-B
STA-B-139A	SP3-3 1 3		1002.5	5.3	36.0	18.0	8.0	11.0	88.0	0.2	0.60						CS-B
STA-B-139A	SP3-3 1 3		1002.5	10.2	41.0	20.0	21.0	37.0	62.0	0.1	0.55	550	430	202	37.9	20.2	CS-B
STA-B-139A	SP3-3 1 3		1002.5	10.2	36.0	22.0	12.0	22.0	77.0	0.6	0.54						SBS
STA-B-139A	SP3-3 1 3		1002.5		47.0	21.0	26.0	45.0	50.0	0.0	0.50						SBS
STA-B-139A	SP3-3 1 4		1002.5	6.2	37.0	19.0	10.0	20.0	71.0	0.1	0.62						CS-B
STA-B-139A	SP3-3 1 4		1002.5	6.2	35.0	19.0	6.0	11.0	88.0	0.2	0.51						CS-B
STA-B-139A	SP3-3 1 4		1002.5	8.7	32.0	20.0	12.0	22.0	75.0	0.2	0.53						CS-B
STA-B-139A	SP3-3 1 4		1002.5	8.7	50.0	21.0	27.0	42.0	57.6	0.0	0.64						CS-B
STA-B-139A	SP3-3 1 5		1002.5	11.0	41.0	20.0	21.0	36.0	63.7	0.3	0.50	450	500	250	34.3	16.4	CS-B
STA-B-139A	SP3-3 1 5		1002.5	11.3	35.0	20.0	15.0	22.0	77.0	0.3	0.67	650	440	224	36.4	19.0	SBS
STA-B-139A	SP3-3 1 5		1002.5		35.0	20.0	15.0	36.0	64.0	0.0	0.50						SBS
STA-B-139A	SP3-3 1 5		1002.5		35.0	20.0	15.0	35.0	64.0	0.2							SBS
STA-B-139A	SP3-3 1 5		1002.5		35.0	20.0	15.0	36.0	60.0	1.0	0.50						CS-B
STA-B-139A	SP3-3 1 5		1002.5		40.0	21.0	19.0	30.6	60.5	0.9	0.49						CS-B
STA-B-139A	SP3-3 1 5		1002.5		31.0	19.0	12.0	14.0	81.0	0.9	0.45						CS-B
STA-B-139A	SP3-6 1 1		1002.4	10.7	39.0	24.0	15.0	35.0	65.0	0.0	0.43	425	384	130	23.4	17.0	CS-B
STA-B-139A	SP3-6 1 1		1002.4	10.7				35.0	65.0								SBS
SAMPLES FROM WEST DIVERSION TUNNEL - ISLTY																	
LD-3	1		1006.6	10.6	40.0	26.0	22.0	52.0	43.0	5.0	0.44	300	55	55	15.3	15.3	SBS (SBS)
LD-3	2		1006.6									400	130	127	19.0	17.6	SBS (SBS)
LD-3	3		1006.6									400	354	185	17.6	13.0	SBS (SBS)
LD-4	1		1006.6	17.1	40.0	30.0	20.0	50.0	42.0	0.0	0.50	300	95	83	17.6	15.4	SBS (SBS)
LD-4	2		1006.6									400	154	130	14.0	12.2	SBS (SBS)
LD-4	3		1006.6									1200	300	255	15.0	12.0	SBS (SBS)

* NON ELASTICIZED TEST

1 ELASTICIZED SEAR SAMPLE

ALL SAMPLES WERE SEAR IN THE BS DIRECTION, UNLESS OTHERWISE SPECIFIED

CS CLAYSTONE

CS-L CLAYSTONE - LOWER ADJACENT ROCK

CS-B CLAYSTONE - UPPER ADJACENT ROCK

SBS SEAM MATERIAL - SMALL DIAMETER SAMPLES FROM ROSE

SBS SEAM MATERIAL - LARGE DIAMETER CORE SAMPLES

TOTAL NO. OF β_r = 223

B13.0 ASSESSMENT OF THE SHEAR STRENGTH ALONG SEAMS

B13.1 GENERAL

Two sets of shear strength parameters for the bedrock are required for the stability analyses. These comprise the shear strength along the seams, and the shear strength of the rock in shear across the bedding planes.

The shear strength along the seams is discussed in the following section. The cross bedding shear strength will be discussed in the next section.

A geological assessment of the seams present at the project site and their location is discussed in the previous sections and given in Tables B10-1, B10-2, B10-3, B10-4 and B10-5. In this section the shear strength of the continuous shear seams important in the design of the different structures has been assessed.

During the preliminary engineering phase, the site investigation and laboratory test data seemed to suggest that, with the exception of the seams within Structural Unit No. 1, there was a uniformity in the residual and available shear strength measured on samples taken from seams at all elevations. The data had the normal variation and scatter, but it appeared that for design purposes, an effective residual angle of shearing resistance of 16° with a geological component of 1.5° could be conservatively used for all rock above the Basal Sandstone. For preliminary design a horizontal seam with an effective angle of shearing resistance of 17.5° was assumed to exist at the most

critical elevation below structures for stability. This simplified perception of the site changed when it became apparent that some of the seams found in shaft SH-86-S707, located beneath the Spillway headworks, had residual angles of shearing resistance lower than 16° . After that time, detailed analyses of the presence, location, and characteristics of each seam were used to establish the most appropriate design parameters.

To determine if certain seams had lower values of shearing resistance than others, it was necessary to collate all the laboratory testing on a seam by seam basis.

The following laboratory testing data was compiled for each sample taken from each of the continuous seams identified in Section B10.0.

- residual angle of shearing resistance
- peak angle of shearing resistance
- clay content
- liquid limit

In the assessment of shear strength along the seams, the peak angle of shearing resistance measured in the laboratory is referred to as the in situ angle of shearing resistance for that particular sample. The main reason was to distinguish between the real peak angle of shearing resistance of the unsheared rock from one which is at the softened state somewhere between the real peak and the residual state.

Using the data gathered for each seam sample, the following relationships were examined.

- residual angle of shearing resistance versus in situ angle of shearing resistance.
- residual angle of shearing resistance versus clay content and liquid limit.

A detailed seam by seam discussion of these results follows in the next sections.

B13.2 SEAMS IN VALLEY BOTTOM

B13.2.1 General

The location and geological assessment of seams in the valley bottom are given on Table B10-3, B10-4 and B10-5, and on Plate B-30. Also shown on Plate B-30 are the individual test results of liquid limit, clay content, residual angle of shearing resistance and in situ angle of shearing resistance for each sample.

The Basal Sandstone Sequence extends from elevation 1006 m to 1043 m (dam axis). Hence, for all the potential sliding surfaces below this Basal Sandstone, the seams must pass through approximately 37 m of strong sandstone with a high cross-bedding angle of shearing resistance ($\phi' = 60$ degrees).

A sensitivity analysis has been carried out for a potential seam just below the Basal Sandstone (elevation 1004m). In this analysis the angle of shearing resistance along the seam and the cross-bedding shearing resistance in the Basal Sandstone were varied (Appendix C, Plate C-3). This

analysis shows that in order for a seam, which is located just below the Basal Sandstone, to be significant for the stability of the dam, it must have an angle of shearing resistance equal to or less than 3 degrees. The representative residual angle of shearing resistance determined for seam V8 located just below the Basal Sandstone is 12.5 degrees (Plate B-102). Hence, seams V1 to V8 (Table B10-3) which are located below the Basal Sandstone have not been considered in the stability analysis of the dam.

The bedrock surface in the river valley at dam foundation is at elevation 1048, hence, seams V18 to V21 are not present in the foundation of the dam. These four seams, however, have been considered in the stability analysis of the abutment sections of the dam and the abutment slopes.

As shown on Plates B-6 and B-36, plotting drill hole data collected in the river valley in plan, indicates that in the downstream section of the dam, the upper claystone layer has been replaced by channel sandstone and siltstone for almost 70 percent of the dam foundation. As the result, seam V17 will not be present in the downstream section of the dam foundation. In the river valley in the upstream section of the dam, the upper claystone layer is 6 m thick at the upstream toe of the dam and it thins down to almost 0.5 m at the middle of the upstream section. Also, as shown on Plates B-6 and B-36, in the river valley in the upstream section of the dam, almost 50 percent of this claystone layer has been eroded away leaving sandstone at the bedrock surface.

In Tables B10-4 and B10-5, the continuous seams in the valley bottom have been identified for the upstream and downstream sections.

B13.2.2 Upstream Seams

In the upstream section of the dam there are eleven continuous and ten discontinuous seams. The discontinuous seams have not been considered in the design of the dam. Of the continuous seams, eight are thick and the rest thin.

Four of the eleven continuous seams (V2, V3, V5 and V8) are below the Basal Sandstone and are not significant in the design of the dam. Seams V18 and V20 are not present in the river valley. The remaining five seams (V10, V12, V15, V16 and V17) have been considered in the design of the upstream section of dam.

B13.2.3 Downstream Seams

In the downstream section of the dam there are five continuous and 16 discontinuous seams. The discontinuous seams have not been considered in the design of the dam. All of the continuous seams are thin. Of these, two (V4 and V8) are below the Basal Sandstone and are not significant in the design of the dam. Seam V17 is not present in the downstream section of dam. The remaining two seams (V10 and V11) have been considered in the design of the downstream section of the dam.

B13.2.4 Shear Strength Along Seams in Valley Bottom

General

There are 21 seams in the valley bottom as listed in Table B10-3. Of these 21 seams, 8 seams, (V1 to V8 inclusive) are located below the Basal Sandstone and are insignificant in the design of the dam. From the remaining 13 seams, five of them (V9, V13, V14, V19 and V21) are discontinuous seams and will not be discussed any further. Seams V18 and V20 are not present across the entire river valley, but they are of significance to the design of the abutment section of the dam.

Seam V8 can only be significant if its angle of shearing resistance becomes equal to or less than 3 degrees.

The shear strength of seams, V8, V10, V11, V12, V15, V16, V17 and V18 has been investigated. For these seams, all of the direct shear test results located on the same seam have been plotted on one shear stress versus normal stress plot.

Seam V8

Seam V8 is located just below the Basal Sandstone in the Lower Mudrock Sequence. Its reference elevation at the dam axis is 1003.1 to 1005.9 m. The thickness of seam V8 varies from less than 1 mm to 10 mm. It has been designated as a thick seam for the upstream section of the dam and as a thin seam for the downstream section of the dam. Plate B-102 shows the residual and in situ angles of shearing resistance for this seam. The residual angles of shearing resistance measured on samples taken from this seam are 12.2 and 12.9

degrees. The determined representative residual angle of shearing resistance is 12.5 degrees. The clay content and liquid limit values measured for this seam are 20 percent and 43, respectively.

Seam V10

Seam V10 is located in a claystone layer within the Basal Sandstone. Its reference elevation at the dam axis is 1025.6 m. The thickness of this seam varies from less than 1 mm to 12 mm. It has been assessed as a thick seam in the upstream shell and a thin seam in the downstream shell. Plates B-103 to B-105 show the residual strength, in situ strength and residual versus in situ strength plots. As shown on Plate B-103, the determined representative residual shear strength for this seam is 13.5 degrees. Plate B-106 shows the histogram of the residual shear strength measured on samples taken from this seam. From all the residual angles of shearing resistance measured, 25 percent of them are less than 13.5 degrees, that is, three out of twelve having measured values of 13.4, 13.1 and 13 degrees. The seventy-five percent of the values that are higher than 13.5 degrees range between 13.9 and 25.2 degrees.

The measured residual shear strength values vary between 13 degrees and 25.2 degrees, with a mean value of 17.4 degrees. Plate B-107 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 18.1 to 60 percent, with an average value of 38.3 percent. The liquid limit values vary between 32 to 46.7, with an average value of 38. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate a high

variability along seam V10, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value for this seam.

Plate B-105 shows the plot of in situ versus residual angle of shearing resistance. Three results are from tests carried out on the seam samples obtained from the test shaft SH-85-95, while the remaining nine results are from tests carried out on the seam samples obtained from the drillholes. Comparing the in situ and residual angles of shearing resistance, from the three test results on the seam samples obtained from the test shaft, one is in residual state, but the other two show in situ angles of shearing resistance which are approximately 1 degree higher than residual. Therefore the representative residual angle of shearing resistance for this seam was determined to be 13.5 degrees.

Plates B-108 and B-109 show the variation of residual angles of shearing resistance with clay content and liquid limit. The same material was used in the direct shear tests and in the index tests. There are no clear correlations between the residual angle of shearing resistance and the clay content and liquid limit.

Based on the representative residual angle of shearing resistance value of 13.5 degrees, from Plates B-108 and B-109, the representative clay content and liquid limit values for this seam are 37 percent and 40, respectively.

Seam V11

Seam V11 is located in a claystone layer within the Basal Sandstone. Its reference elevation at the dam axis is 1027.6 m. The thickness of this seam varies from 4 mm to 12 mm. It has been designated as a thick seam. Plate B-110 shows the residual strength and in situ strength plots for this seam. As shown on Plate B-110, the representative residual shear strength for this seam was determined to be 14.5 degrees. Plate B-111 shows the histogram of the residual shear strength measured on samples taken from this seam. The measured residual angles of shearing resistance vary between 14.4 degrees and 19.3 degrees, with a mean value of 16.4 degrees. From all the residual angles of shearing resistance measured, 25 percent of them are less than 14.5 degrees. This is one out of four with the measured value of 14.4 degrees. The other three residual strength results range between 15.1 to 19.3 degrees.

Also, shown on Plate B-110 is the measured peak strength of $c'p = 80$ kPa and $\phi'p = 18.3$ degrees. The representative clay content and liquid limit values for this seam are 36 percent and 34, respectively.

Seam V12

Seam V12 is located in a claystone layer within the Basal Sandstone. Its reference elevation at the dam axis is 1030.7 m. The thickness of this seam varies from 10 mm to 30 mm. It has been assessed as a thick seam. Plates B-112 to B-114 show the residual angle of shearing resistance, in situ angle of shearing resistance and residual angle of shearing resistance versus in situ angle of shearing resistance plots.

As shown on Plate B-112, the representative residual angle of shearing resistance was determined to be 12 degrees. Plate B-115 shows the histogram of the residual shear strength measured on samples taken from seam V12. From all the residual angles of shearing resistance measured, 20 percent of them are less than 12 degrees. These are three out of 15 with the measured values of 11.9, 11.5 and 10.9 degrees. This results in a difference of 1.1 degrees between the lowest residual angle of shearing resistance measured on samples taken from this seam (10.9 degrees) and the representative value of this seam (12 degrees). The remaining eighty percent of the residual strength values measured are higher than 12 degrees with a range between 12.4 degrees to 29.4 degrees.

The measured residual shear strength values vary between 10.9 degrees and 29.4 degrees, with a mean value of 20.2 degrees. Plate B-116 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 17.5 to 57 percent, with an average value of 41 percent. The liquid limit values vary between 27.3 to 42.6, with an average value of 42. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam V12, which supports assigning a representative value of residual angle of shearing resistance greater than the measured minimum residual value for this seam.

Plate B-114 shows the comparison between the residual and in situ angle of shearing resistance. Five results are from tests carried out on the seam samples obtained from the test shaft SH-85-D95, three results are from tests carried out on

the seam samples obtained from the drillholes, and seven results are from tests conducted on intact claystone samples obtained from drillholes. From the results of test shaft seam samples, 60 percent are at the residual state with in situ and residual angles of shearing resistance being equal. The remaining 40 percent of the results of the test shaft seam samples show a very small difference between the in situ and residual angles of shearing resistance.

The results from the seam samples obtained from the drillholes show a higher in situ strength compared to those from the seam samples obtained from the test shaft. This trend has generally been seen in all test results.

Index tests were carried out on the samples used in the direct shear tests. Plates B-117 and B-118 show the plots of the residual angle of shearing resistance versus the clay content and liquid limit for each individual test along this seam. There are good correlations between the residual angle of shearing resistance, clay content and liquid limit. The general trend is that by increasing clay content and liquid limit, the residual angle of shearing resistance decreases.

From Plates B-117 and B-118, for the representative residual angle of shearing resistance of 12 degrees, the representative clay content and liquid limit values for this seam are 51 percent and 42, respectively.

Seam V15

Seam V15 is located in the Upper Mudrock Sequence overlying the Basal Sandstone. Its reference elevation at the dam axis is 1043.9 m. The thickness of this seam varies up to 5 mm. It has been designated as a thick seam.

Plate B-119 shows the residual strength and in situ strength plot.

As shown on Plate B-119, the determined representative residual angle of shearing resistance along this seam is 22.5 degrees. Plate B-120 shows the histogram of the residual shear strength measured on samples from this seam. The measured residual shear strength values vary between 22.4 degrees and 29.8 degrees, with a mean value of 25.7 degrees. From all the residual angles of shearing resistance measured, 20 percent of them are less than 22.5 degrees. This is one out of 5 results with the measured value of 22.4 degrees. Eighty percent of the residual strength values measured are higher than 22.5 degrees with a range between 23.7 to 29.8 degrees.

For the representative residual angle of shearing resistance equal to 22.5 degrees, the representative clay content and liquid limit values for this seam are 40 percent and 36, respectively.

Seam V16

Seam V16 is located in the Upper Mudrock Sequence overlying the Basal Sandstone. Its reference elevation at the dam axis is 1046.8 m. The thickness of this seam is up to 1 mm. It has been assessed as a thin seam.

Plates B-121 and B-122 show the residual and in situ shear strength plots. As shown on Plate B-121 the representative residual angle of shearing resistance along this seam was determined to be 15.5 degrees. Plate B-124 shows the

histogram of the residual angle of shearing resistance measured on samples taken from this seam. The measured residual shear strength values along this seam vary between 14.5 degrees and 26 degrees, with a mean value of 18.3 degrees. From all the residual angles of shearing resistance measured, 32 percent of them are less than 15.5 degrees. These are 6 out of 19 results with the measured values of 14.5, 14.7, 14.9, 15.0, 15.0 and 15.2 degrees. This results in a difference of one degree between the lowest residual angle of shearing resistance measured on samples taken from this seam (14.5 degrees) and the representative one for this seam (15.5 degrees). The remaining 68 percent of the residual strength values measured are higher than 15.5 degrees with a range between 15.7 and 26 degrees. The variations in the measured angles of shearing resistance indicate a variability along this seam which supports assigning a value of the representative residual angle of shearing resistance for this seam which is greater than the minimum residual value.

Plate B-123 shows the values of the in situ shear strength versus the residual shear strength. Thirty-seven percent of the results (7 out of 19) are from tests carried out on the large diameter core samples of the seam taken from the test shaft SH-87-D14. The remaining results are from tests carried out on the intact claystone samples. All the results for the large diameter core samples have an in situ angle of shearing resistance higher than the residual angle of shearing resistance. The minimum measured in situ angle of shearing resistance is 23.2 degrees. The minimum difference between the in situ and residual angles of shearing resistance is 3.7 degrees.

For the representative residual angle of shearing resistance of 15.5 degrees, the representative clay content and liquid limit values for this seam are 39 percent and 41, respectively.

Seam V17

Seam V17 is located in the Upper Mudrock Sequence overlying the Basal Sandstone. Its reference elevation at the dam axis is 1047.7 m. The thickness of this seam varies from less than 1 mm to 10 mm. This seam has been designated as a thick seam.

Plates B-125 and B-126 show the residual and in situ shear strength plots. As shown on Plate B-125, the representative residual angle of shearing resistance along this seam is determined to be 21 degrees. Plate B-127 shows the histogram of the residual shear strength for this seam. The residual shear strength values measured on samples taken from this seam vary between 20.5 degrees and 29.7 degrees, with a mean value of 26.1 degrees. From all the residual angles of shearing resistance measured, 17 percent of them are less than 21 degrees. This is one out of six results with a measured value of 20.5 degrees. The remaining 83 percent of the residual strength values measured are higher than 21 degrees with a range between 24.2 and 29.7 degrees.

All the available test results for this seam are from shear tests carried out on the samples of intact claystone, hence it is not possible to assess the in situ state of this seam from the shear test results. For the representative residual angle of shearing resistance of 21 degrees, the representative clay content and liquid limit values for this seam are 18 percent and 30, respectively.

Seam V18

Seam V18 is located in the Upper Mudrock Sequence overlying the Basal Sandstone. Its reference elevation at dam axis is 1049.4 m. The thickness of this seam varies from less 1 mm to 32 mm. This seam has been designated as a thin seam. The top of bedrock in the river valley is at elevation 1048 m, hence, this seam is not present in the foundation of the dam in the river valley. Seam V18 will be considered only in the design of river slopes and the abutment sections of the dam.

Plates B-128 to B-130 show the residual strength, in situ strength and residual angle of shearing resistance versus in situ angle of shearing resistance plots.

As shown on Plate B-128, the representative residual angle of shearing resistance along this seam was determined to be 15 degrees. Plate B-131 shows the histogram of the residual strength for this seam. From all the residual angles of shearing resistance measured on samples taken from this seam, 30 percent of them are less than 15 degrees. There are four out of 13 results with measured values of 12, 12.2, 12.7 and 13 degrees. This results in a difference of 3 degrees between the lowest single residual angle of shearing resistance measured from samples taken from this seam (12 degrees) and the representative value for this seam (15 degrees). The remaining 70 percent of the residual strength values measured are higher than 15 degrees with a range between 15.2 degrees to 23.7 degrees.

The measured residual shear strength values vary between 12 degrees and 23.7 degrees, with a mean value of 16.6 degrees. Plate B-132 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 34 to 58 percent, with an average value of 43.2 percent. The liquid limit values vary between 29.6 to 49.4, with an average value of 38. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along the seam V18, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value for this seam.

Plate B-130 shows the plot of residual angle of shearing resistance versus the in situ angle of shearing resistance. Four out of 13 results (30 percent) are in the residual state with in situ and residual angles of shearing resistance being equal. The remaining 9 out of 13 results (70 percent) show that the in situ strengths are higher than the residual strength. The smallest difference between the in situ and the residual strength is about one degree.

Index tests were carried out on the samples used in the direct shear tests. Plates B-133 and B-134 show the variation of the residual angle of shearing resistance with the clay content and liquid limit for each individual test along this seam. There are good correlations between the residual angle of shearing resistance, clay content and liquid limit. The general trend is that by increasing clay content and liquid limit the residual angle of shearing resistance decreases.

From Plates B-133 and B-134 for the representative residual angle of shearing resistance of 15 degrees, the representative clay content and liquid limit values for this seam are 42 percent and 36, respectively.

B13.2.5 Summary of Continuous Seams and Their Determined Representative Residual Shear Strengths

As discussed, the continuous seams in the valley bottom are V8, V10, V11, V12, V15, V16, V17 and V18. The shear strength and index properties of these seams are given in Table B13-1.

The significance of these seams on the design of the dam and the selection and design seams will be discussed in a later section.

TABLE B13-1
CONTINUOUS SEAMS IN VALLEY BOTTOM
AND THEIR REPRESENTATIVE RESIDUAL SHEAR STRENGTH

SEAM NO.	ELEVATION AT DAM AXIS (m)	REPRESENTATIVE LIQUID LIMIT	REPRESENTATIVE CLAY CONTENT (%)	REPRESENTATIVE RESIDUAL ANGLE OF SHEARING RESISTANCE (degrees)
V8	1003.1-1005.9	43	20	12.5
V10	1025.6	40	37	13.5
V11	1027.6	34	36	14.5
V12	1030.7	42	51	12.0
V15	1043.9	36	40	22.5
V16	1046.8	41	39	15.5
V17	1047.7	30	18	21.0
V18	1049.4	36	42	15.0

B13.3 SEAMS IN ABUTMENTS

B13.3.1 General

The location and geological assessment of seams in the right bank are given in Tables B10-1 and B10-2 and on Plates B-26 to B-29. The investigation concentrated on the area to be occupied by the spillway. The individual test results of liquid limit, clay content, residual angle of shearing resistance and in situ angle of shearing resistance are also given on Plates B-26 to B-29.

The assessment of the right abutment seams is based on the data primarily from drillholes and trenches supplemented by data from the test shaft SH-86-S707. The seams are identified according to a reference elevation on the spillway centreline which is subparallel to the strike of the beds.

Results of the bedrock mapping in the inlet and outlet portals excavation and in the access road exposures between the portals on the left abutment indicated a good correlation of continuity between the carbonaceous beds and the continuous seams in the right and the left abutments, taking into account the general 0.6 degrees upstream dip of the beds. Hence, the seams located in the spillway area, inlet portal excavation and the access road exposures can be considered to be continuous accross the right and left abutments. These will be referred to as the seams in the abutments.

In the abutments, up to elevation 1108 m, 11 continuous and six discontinuous seams have been identified and are listed in Table B10-2. Of these 11 continuous seams, 10 are thick and one (R7) is thin. The discontinuous seams (R2, R3, R4, R5, R11 and R12) have not been considered in the design. Seam R10 is not present at the foundation of the spillway headworks structure, and in other locations, it merges with the seam R9, hence seam R10 has not been considered further. Above elevation 1108 m, one additional continuous seam (R18) with reference elevation 1115 m, at spillway centreline has been considered for design.

B13.3.2 Shear Strength Along Seams in Abutments

General

In this section the shear strength of the seams R1, R6, R7, R8, R9, R13, R14, R16, R17 and R18 will be discussed. All of the direct shear test results for each of these seams have been plotted on one shear stress versus normal stress plot.

Seam R10 is discontinuous at the foundation of the spillway headworks structure. As there are no shear strength data; for seam R15, the shear strength data for seam R16 have been used.

A very detailed shear and index testing program has been carried out on the large diameter core samples taken from seams No.2 and No.3 in the upstream diversion tunnels portal. Although these correlate to seams R9 and R8, respectively, the results for seams No.2 and No.3 are discussed separately.

Also, some large diameter cores have been taken from seam R1 in the access road between the upstream and downstream diversion tunnels portals. The results from this location have been reported both separately and combined with those results for seam R1 from the spillway area.

The test results from the spillway area trenches have been combined with those results from the test shaft and drill holes from the spillway area.

Seam R1

Seam R1 is located in the Upper Mudrock Sequence in the abutments. Its reference elevation at the spillway centreline is 1068.2 m. The thickness of seam R1 varies from less than 1 mm to 65 mm. It has been assessed as a thick seam.

Plates B-135 to B-137 show the residual shear strength, in situ shear strength and residual versus in situ angle of shearing resistance plots for all the measured values for seam R1, including those from the left bank. As shown on Plate B-135, the representative residual shear strength for this seam was determined to be 10.5 degrees. Plate B-138 shows the histogram for the residual angles of shearing resistance measured on samples taken from this seam. From all the residual angles of shearing resistance measured, 14 percent of them are less than 10.5 degrees. This is 3 out of 22 results with measured values of 8.7 8.9 and 10 degrees. The maximum difference between the lowest residual angle of shearing resistance measured (8.7 degrees) and the one assigned for this seam (10.5 degrees) is 1.8 degrees.

The remaining 86 percent of the residual angle of shearing resistance results are higher than 10.5 degrees with a range between 10.7 degrees and 14.7 degrees.

The measured residual shear strength values vary between 8.7 degrees and 14.7 degrees, with a mean value of 11.6 degrees. Plate B-139 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 48 to 70 percent, with an average value of 62.5 percent. The liquid limit values vary between 44 to 64.1, with an average value of 49.5. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam R1, which supports assigning a value of residual angle of shearing resistance greater than the measured minimum residual value for this seam.

Plate B-137 shows the values of in situ angle of shearing resistance versus the residual angle of shearing resistance. As shown on Plate B-137, all of the in situ angles of shearing resistance are higher than the residual values. The smallest difference between the residual and in situ angle of shearing resistance is 2.4 degrees. However, the minimum measured in situ angle of shearing resistance is 11 degrees.

Index tests were carried out on the samples used for the direct shear tests. Plates B-140 and B-141 show the residual angle of shearing resistance versus the clay content and liquid limit for individual tests along this seam. From Plates B-140 and B-141 for the representative residual angle of shearing resistance of 10.5 degrees, the representative clay content and liquid limit values for this seam are 65 percent and 54, respectively.

Four large diameter core samples were taken from seam R1 in test trench DT-85-G75 excavated on the left abutment on the existing access road (location of this test trench is shown on Plate B-36). Fifteen direct shear tests were carried out on these samples. The results of these tests are included with the rest of the results for seam R1.

In order to show the range of variation in the measured angle of shearing resistance from a particular location, the results for test trench DT-85-G75 are shown on Plates B-142 to B-148, independently. Plate B-142 shows the value of residual angle of shearing resistance for seam R1 from this particular location. The representative residual strength value is determined to be 11 degrees. Plate B-145 shows the histogram for the residual angles of shearing resistance measured on samples taken from seam R1 in test trench DT-85-G75. From all the residual angles of shearing resistance measured along this seam in this particular location, 20 percent of them are less than 11 degrees. This is 3 out of 15 results with all three measured values of 10.9 degrees. The remaining 80 percent of the residual angles of shearing resistance values measured are higher than 11 degrees with a range between 11.3 degrees to 14.7 degrees.

The range of variation in the residual angle of shearing resistance is between 10.9 and 14.7 degrees. In other words, the measured residual angles of shearing resistance of samples taken from one particular location can vary by as much as four degrees.

Plates B-143 and B-144 show the in situ strength and the residual versus in situ angle of shearing resistance. The lowest in situ angle of shearing resistance measured is 15 degrees which is 4 degrees higher than the representative residual angle of shearing resistance of 11 degrees. Hence, the value of 11 degrees as the representative residual angle of shearing resistance for this seam is conservative.

Plates B-146 and B-147 show the residual angle of shearing resistance values versus clay content and liquid limit. Plate B-148 shows the histogram of the clay content and the liquid limit. The clay content ranges between 46 percent to 69 percent and liquid limit ranges between 44.2 to 64.1. For the representative residual angle of shearing resistance of 11 degrees, the representative clay content and liquid limit values for this seam are 62 percent and 60, respectively.

These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam R1, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

Seam R6

Seam R6 is located in the Upper Mudrock Sequence in the abutments. Its reference elevation at the spillway centreline is 1084.5 m. The thickness of seam R6 varies from less than 1 mm to 100 mm. It has been assessed as a thick seam.

Plate B-149 shows the residual and in situ shear strengths for this seam. The representative residual angle of shearing resistance determined for this seam is 12.5 degrees. From three residual angles of shearing resistance measured on samples taken from this seam, one is less than 12.5 degrees with a value of 12.3 degrees. The remaining two residual angles of shearing resistance measured along this seam are 13.5 and 15.8 degrees. As shown on Plate B-149, the in situ angle of shearing resistance measured along this seam is 19 degrees. Hence, the representative residual angle of shearing resistance of 12.5 degrees is a conservative value.

The measured residual shear strength values vary between 12.3 degrees and 15.8 degrees, with a mean value of 13.9 degrees. Plate B-150 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 31 to 52.5 percent, with an average value of 49 percent. The liquid limit values vary between 31 to 51, with an average value of 43.

The representative clay content and liquid limit values for this seam are 49 percent and 43, respectively.

Seam R7

Seam R7 is located in the Upper Mudrock Sequence in the abutments. Its reference elevation at the spillway centreline is 1086.5 m. The thickness of seam R7 is predominantly less than 1 mm. It has been assessed as a thin seam.

Plate B-151 shows the residual and in situ shear strengths for this seam. The representative residual angle of shearing resistance determined for this seam is equal to 12 degrees. From four residual angles of shearing resistance measured on samples taken from this seam, two are less than 12 degrees with a value of 11.9 degrees for both. The remaining two residual angles of shearing resistance are 12.2 and 12.8 degrees. As shown on Plate B-151, the in situ angles of shearing resistance measured along this seam are higher than the residual shear strength value. Hence, the representative residual angle of shearing resistance of 12 degrees is a conservative value.

The measured residual shear strength values vary between 11.9 degrees and 12.8 degrees, with a mean value of 12.2 degrees. Plate B-152 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 44.5 to 61 percent, with an average value of 53.6 percent. The liquid limit values vary between 39 to 52.4, with an average value of 47.

The representative clay content and liquid limit values for this seam are 57 percent and 49, respectively.

Seams R6 and R7 Combined

Seams R6 and R7 are approximately two metres apart at the spillway centreline, however, in other areas they may merge and become one seam. The laboratory test results along these two seams were combined. Plates B-153 to B-155 show the residual angle of shearing resistance, the in situ angle of shearing resistance and the residual shear strength

versus the in situ shear strength plots. As shown on Plate B-153, the representative residual shear strength for seams R6 and R7 combined was determined to be 12 degrees. Plate B-156 shows the histogram from the residual angles of shearing resistance measured for seams R6 and R7. From all the residual angles of shearing resistance measured, 29 percent of them are less than 12 degrees. These are two out of seven results with the measured values of 11.9 for both of them. The difference between the lowest residual angle of shearing resistance measured (11.9 degrees) and the assigned one (12 degrees) is 0.1 degrees. The remaining 71 percent of the residual angles of shearing resistance measured are higher than 12 degrees with a range between 12.2 and 15.8 degrees.

The measured residual shear strength values vary between 11.9 degrees and 15.8 degrees, with a mean value of 12.9 degrees. Plate B-157 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 31 to 61 percent, with an average value of 49.9 percent. The liquid limit values vary between 31 to 52.4, with an average value of 44.8. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seams R6 and R7 combined, which supports assigning a value of residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-155 shows the values of in situ angle of shearing resistance versus the residual angle of shearing resistance. All the in situ shear strength values are higher than the residual shear strength values. The

smallest difference between the residual and the in situ shear strength is 6.5 degrees. Hence, the representative residual angle of shearing resistance of 12 degrees is a conservative value.

Index tests were carried out on the samples used for the direct shear tests. Plates B-158 and B-159 show the residual angle of shearing resistance versus the clay content and liquid limit for seams R6 and R7 combined. The representative clay content and liquid limit are 55 percent and 48, respectively.

Seam R8 (Excluding the Results from Upstream Diversion Tunnel Portal)

Seam R8 is located in the Upper Mudrock Sequence in the abutments. Its reference elevation at the spillway centreline is 1087.5 m. The thickness of this seam varies from less than 1 mm to 80 mm. It has been designated as a thick seam.

Plates B-160 to B-162 show the residual shear strength, the in situ shear strength and the residual versus in situ shear strength plots. As shown on Plate B-160, the representative residual angle of shearing resistance determined for this seam is 12 degrees.

Plate B-163 shows the histogram of the residual angles of shearing resistance measured on samples taken from this seam; 13 percent of them are less than 12 degrees. This is one out of eight results with the measured value of 11.7 degrees. The remaining 87 percent of the results are higher than 12 degrees with a range between 12.2 to 15.9 degrees.

The measured residual shear strength values vary between 11.7 degrees and 15.9 degrees, with a mean value of 13.2 degrees. Plate B-164 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 36 to 60 percent, with an average value of 51.1 percent. The liquid limit values vary between 37.8 to 54.3, with an average value of 45.8. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam R8, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-162 shows the plot of the in situ shear strength versus the residual shear strength. All the in situ shear strength values measured along this seam are higher than the residual shear strength. The smallest difference between the residual and the in situ angles of shearing resistance is 7.5 degrees.

Plates B-165 and B-166 show the residual angle of shearing resistance versus the clay content and liquid limit. The representative clay content and liquid limit values for this seam, considering the representative residual angle of shearing resistance of 12 degrees, are 57 percent and 48, respectively.

Seam R8 (Including the Results from Upstream Diversion Tunnel Portal)

Seam No. 3 is located at the elevation 1082 m in the upstream diversion tunnel portal. It corresponds to the seam R8 in the spillway area in the right bank. The results

from the Seam No. 3 have been combined with the rest of the results on seam R8 and they have been discussed in this Section.

Plate B-167 to B-169 shows the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. As shown on Plate B-167 the representative residual angle of shearing resistance determined for this seam is 12 degrees.

Plate B-170 shows the histogram of the residual angles of shearing resistance measured on samples taken from this seam. From all the residual angles of shearing resistance measured along this seam, 12 percent of them are less than 12 degrees. They are five out of 40 results with the measured values of 10.3, 11.1, 11.7, 11.7 and 11.9 degrees. The remaining 88 percent of the results are higher than 12 degrees with a range between 12.2 to 23.4 degrees. The difference between the lowest residual angle of shearing resistance measured (10.3 degrees) and the representative value for this seam (12 degrees) is 1.7 degrees.

The measured residual shear strength values vary between 10.3 degrees and 23.4 degrees, with a mean value of 16.8 degrees. Plate B-171 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 27.6 to 64 percent, with an average value of 44.8 percent. The liquid limit values vary between 38 to 56.8, with an average value of 46. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam R8, which supports assigning of a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-169 shows the values of in situ shear strength versus the residual shear strength. Ninety percent of the results are from the tests carried out on the large diameter core samples of the seam. Five percent of the results are from tests carried out on the intact claystone samples. The remaining five percent of the results are from tests carried out on the samples of the seam taken from the drill holes. From the results of the large diameter core samples, three percent (one out of 36) are at the residual state with the in situ and the residual angles of shearing resistance being equal. For the remaining 97 percent (35 out of 36) of the results of the large diameter core samples, the in situ shear strength is a minimum of one degree greater than the residual shear strength.

Plates B-172 and B-173 show the residual angle of shearing resistance versus the clay content and liquid limit. The representative clay content and liquid limit values for this seam, considering the representative residual angle of shearing resistance of 12 degrees, are 55 percent and 50, respectively.

Seam R9 (Excluding the Results from Upstream Diversion Tunnel Portal)

Seam R9 is located in the Upper Mudrock Sequence in the abutments. Its reference elevation at the spillway centreline is 1088.5 m. The thickness of this seam varies from less than 1 mm to 100 mm. It has been assessed as a thick seam.

Plates B-174 to B-176 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. The representative residual angle of shearing resistance determined for this seam is 11 degrees.

Plate B-177 shows the histogram for the residual angles of shearing resistance measured on samples taken from this seam. From all the residual angles of shearing resistance measured along this seam, 38 percent of them are less than 11 degrees. These are 5 out of 13 results with the measured values of 8.3, 9.9, 10.3, 10.5 and 10.9 degrees. The difference between the lowest measured residual angle of shearing resistance (8.3 degrees) and the representative value for this seam (11 degrees) is 2.7 degrees. The remaining 62 percent of the results are higher than 11 degrees with a range between 11.2 degrees to 16 degrees.

The measured residual shear strength values vary between 8.3 degrees and 16 degrees, with a mean value of 11.8 degrees. Plate B-178 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 25 to 70 percent, with an average value of 53.6 percent. The liquid limit values vary between 31.5 to 59.4, with an average value of 46.6. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam R9, which supports assigning a value of representative residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-176 shows the values of in situ shear strength versus the residual shear strength. Seventy percent of the results are from tests carried out on the large diameter core samples of the seam. Seven percent of the results are from tests carried out on the intact claystone samples. The remaining 23 percent of the results are from tests carried out on the samples of the seam taken from the drill holes. From the results of the large diameter core samples, 55 percent are at the residual state with the in situ and the residual angles of shearing resistance being equal. For the remaining 45 percent of the results of the large diameter core samples, the in situ shear strength is a minimum of 3 degrees greater than the residual shear strength.

The results for the seam samples obtained from the drill holes show a higher in situ strength compared to those from the large diameter core samples.

Index tests were carried out on the samples used for the direct shear tests. Plates B-179 and B-180 show the plots of the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance of 11 degrees, the representative clay content and liquid limit values for this seam are 65 percent and 50, respectively.

Seam R9 (Including the Results from Upstream Diversion Tunnel Portal)

Seam 2 is located at the elevation 1083 m in the upstream diversion tunnel portal. It corresponds to the seam R9 in the spillway area in the right bank. The results from the Seam No. 2 have been combined with the rest of the results on seam R9 and they have been discussed in this section.

Plates B-181 to B-183 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. The representative residual angle of shearing resistance determined for this seam is 11 degrees.

Plate B-184 shows the histogram for the residual angles of shearing resistance measured on samples taken from this seam. From all the residual angles of shearing resistance measured, 35 percent of them are less than 11 degrees. These are 8 out of 23 results with the measured values of 8.3, 9.9, 10.0, 10.3, 10.5, 10.6, 10.9 and 10.9 degrees. The difference between the lowest measured residual angle of shearing resistance (8.3 degrees) and the representative value for this seam (11 degrees) is 2.7 degrees. The remaining 65 percent of the results are higher than 11 degrees with a range between 11.2 degrees to 21.3 degrees.

The measured residual shear strength values vary between 8.3 degrees and 21.3 degrees, with a mean value of 12.4 degrees. Plate B-185 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 24 to 70 percent, with an average value of 48.6 percent. The liquid limit values vary between 31.5 to 57.2, with an average value of 47.4. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam R9, which supports assigning a value of residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-183 shows the values of in situ shear strength versus the residual shear strength. Eighty-four percent of the results are from tests carried out on the large diameter core samples of the seam. The remaining 16 percent of the results are from tests carried out on the samples of the

seam taken from the drill holes. From the results of the large diameter core samples, 31 percent are at the residual state with the in situ and the residual angles of shearing resistance being equal. For the remaining 69 percent of the results of the large diameter core samples, the in situ shear strength is a minimum of one degree greater than the residual shear strength.

Index tests were carried out on the samples used for the direct shear tests. Plates B-186 and B-187 show the plots of the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance of 11 degrees, the representative clay content and liquid limit values for this seam are 60 percent and 51, respectively.

Seam R13

Seam R13 is located in the Upper Mudrock Sequence in the abutments. Its reference elevation at the spillway centreline is 1096.5 m. The thickness of this seam varies from less than 1 mm to 90 mm. It has been assessed as a thick seam.

Plate B-188 shows the residual and the in situ shear strengths measured along this seam. The representative residual angle of shearing resistance determined for this seam is 15 degrees.

Plate B-189 shows the histogram of the residual angles of shearing resistance for this seam. The measured residual shear strength values vary between 13.5 degrees and 18.3 degrees, with a mean value of 16.3 degrees. From all the residual angles of shearing resistance measured on samples taken from this seam, 25 percent of them are less than 15

degrees. This is one out four results with the measured value of 13.5 degrees. The difference between the lowest measured residual angle of shearing resistance (13.5 degrees) and the representative value for this seam (15 degrees) is 1.5 degrees. The remaining 75 percent of the results are higher than 15 degrees with measured values of 15.9, 17.4 and 18.3 degrees.

As shown on Plate B-188 one out of four results are in the state of residual, however, the in situ angle of shearing resistance for this seam is 18.5 degrees, with the lowest measured in situ angle of shearing resistance equal to 15.9 degrees.

Seam R14

Seam R14 is located in the Upper Mudrock Sequence in the right abutment. Its reference elevation at the spillway centreline is 1099.8 m. The thickness of this seam varies from less than 1 mm to 20 mm. It has been designated as a thick seam.

Plates B-190 to B-192 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. The representative residual angle of shearing resistance determined for this seam is 15 degrees.

Plate B-193 shows the histogram of the residual angles of shearing resistance measured along this seam. From all the residual angles of shearing resistance measured along this seam, 43 percent of them are less than 15 degrees. They are 3 out 7 results with the measured values of 14.3, 14.6 and 14.9 degrees. The difference between the lowest measured residual angle of shearing resistance (14.3 degrees) and the representative value for this seam (15 degrees) is 0.7

degrees. The remaining 57 percent of the results are greater than 15 degrees with the measured values of 15.1, 15.9, 16.1 and 18.4 degrees.

The measured residual shear strength values vary between 14.3 degrees and 18.4 degrees, with a mean value of 15.6 degrees. Plate B-194 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 43 to 57.5 percent, with an average value of 50.5 percent. The liquid limit values vary between 37.4 to 54.6, with an average value of 44.9. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along the seam R14, which supports assigning a value of residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-192 shows the in situ shear strength versus the residual shear strength plot. All the in situ values of the angles of shearing resistance measured along the seam are higher than the residual values. The smallest difference between the residual and the in situ angles of shearing resistance is 2 degrees, and the lowest in situ shear strength value measured is 17.8 degrees.

Plates B-195 and B-196 show the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance of 15 degrees, the representative clay content and liquid limit values for this seam are 50 percent and 45, respectively.

Seam R15

Seam R15 is located in the Upper Mudrock Sequence in the right abutment. Its reference elevation at the spillway centreline is 1102 m. The thickness of this seam varies from less than 1 mm to 140 mm. It has been designated as a thick seam. There are no shear strength data available for this seam. From a design point of view, this seam and the seam R16 at elevation 1105 m are important for the stability of the spillway approach channel excavated slopes. Hence, as they are only 3 metres apart, the shear strength of seam R16 will also be used for seam R15.

Seam R16

Seam R16 is located in the Upper Mudrock Sequence in the right abutment. Its reference elevation at the spillway centreline is 1105 m. The thickness of this seam varies from less than 1 mm to 60 mm. It has been designated as a thick seam.

Plates B-197 to B-199 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. The representative residual angle of shearing resistance of this seam is determined to be 12.5 degrees.

Plate B-200 shows the histogram of the residual angles of shearing resistance measured along this seam. The measured residual shear strength values vary between 10.8 degrees and 24.9 degrees, with a mean value of 14.9 degrees. Plate B-201 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 42.2 to 60 percent, with an average value of 53 percent. The liquid limit values vary between 39.2 to 51, with an

average value of 45.8. These high variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate great variability along seam R16, and supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

From all the residual angles of shearing resistance measured along this seam, 33 percent of them are less than 12.5 degrees. These are six out 18 results with the measured values of 10.8, 10.9, 11.3, 11.5, 12.3 and 12.4 degrees. The difference between the minimum measured residual angle of shearing resistance (10.8 degrees) and the representative value for this seam (12.5 degrees) is 1.7 degrees. The remaining 67 percent of the results are greater than 12.5 degrees with a range between 12.6 degrees and 24.9 degrees.

Plate B-199 shows the values of the in situ shear strength versus the residual shear strength. Sixty-seven percent of the results are from tests carried out on the large diameter core samples of the seam. Twenty-eight percent of the results are from tests carried out on the samples of the seam taken from the drill holes. Five percent of the results are from tests carried out on the intact claystone samples. From the results of the large diameter core samples, 17 percent (2 out of 12 results) are at the residual state with the in situ and the residual angles of shearing resistance being equal. For the remaining 83 percent of the results of the large diameter core samples (10 out of 12 results), the in situ shear strength is a minimum of 1.3 degrees greater than the residual shear strength. The minimum measured in situ angle of shearing resistance is equal to 12.1 degrees.

The results for the seam samples obtained from the drill holes show a higher in situ strength compared to those from the large diameter core samples, except one value which has a in situ angle of shearing resistance greater than the residual angle of shearing resistance with only 1.5 degrees difference.

It is prudent to assign an angle of shearing resistance higher than the residual shear strength to this seam. This in situ state factor will be discussed later.

Plates B-202 and B-203 show the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance of 12.5 degrees, the representative clay content and liquid limit values for this seam are 60 percent and 50, respectively.

Seam R17

Seam R17 is located in the Upper Mudrock Sequence in the right abutment. Its reference elevation at the spillway centreline is 1107.7 m. The thickness of this seam varies from less than 1 mm to 70 mm. It has been designated as a thick seam.

Plates B-204 to B-206 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. The representative residual angle of shearing resistance of this seam is determined to be 16 degrees.

Plate B-207 shows the histogram of the residual angles of shearing resistance measured on samples taken along this seam. The measured residual shear strength values vary between 15.6 degrees and 17.4 degrees, with a mean value of 16.2 degrees. Plate B-208 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 40 percent to 56 percent, with an average value of 46.5 percent. The liquid limit values vary between 38 and 52, with an average value of 44.2. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam R17, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

From all the residual angles of shearing resistance measured for this seam, 50 percent of them are less than 16 degrees. These are two out of four results with the measured values of 15.6 degrees for both of them. The difference between the measured minimum residual angle of shearing resistance (15.6 degrees) and the representative value (16 degrees) is 0.4 degrees. The remaining 50 percent of the results (2 out of 4) are greater than 16 degrees with the measured values of 16.3 and 17.4 degrees.

Plate B-206 shows the values of the in situ shear strength versus the residual shear strength. Twenty-five percent of the results (one out of four) are from tests carried out on the large diameter core samples of the seam. Fifty percent of the results (two out of four) are from tests carried out on the samples of the seam taken from the drill holes. Twenty-five percent of the results (one out of four) are from tests carried out on the intact claystone samples. All the results of the large diameter core samples are at the

residual state with the in situ and the residual angles of shearing resistance being equal. The minimum measured in situ angle of shearing resistance is 17.4 degrees.

Plates B-209 and B-210 show the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance of 16 degrees, the representative clay content and liquid limit values for this seam are 48 percent and 47, respectively.

Seam R18

As discussed before, approximately above elevation 1105 m, the left (east) bank is overburden and the right (west) bank is weathered rock. On the right bank, above elevation 1115 m there are several seams. For the design purpose, it has been assumed that the seam R18 is at a reference elevation at the spillway centreline of 1115 m, and it can be present at any location between this elevation and the bedrock surface.

Plates B-211 to B-213 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. Based on the measured values, the representative residual angle of shearing resistance determined for this seam is 11.5 degrees.

Plate B-214 shows the histogram of the residual angles of shearing resistance measured on samples taken from seams in the right bank. From all the residual angles of shearing resistance measured, 33 percent of them are less than 11.5 degrees. These are six out of 18 results with the measured values of 9.9, 10.1, 10.2, 10.2, 11 and 11 degrees. The difference between the measured minimum residual angle of shearing resistance (9.9 degrees) and the one assigned for

this seam (11.5 degrees) is 1.6 degrees. The remaining 67 percent of the results are greater than 11.5 degrees with a range between 12 degrees and 22.5 degrees.

Variability in the range residual angles measured for a particular seam is equivalent to the range of values measured for all the seams combined as shown in Table B12-1.

The measured residual shear strength values vary between 9.9 degrees and 22.5 degrees, with a mean value of 14.1 degrees. Plate B-215 shows the histogram of the clay content and liquid limit. The clay content values vary between 34.4 to 65 percent, with an average value of 48.8 percent. The liquid limit values vary between 41.8 to 56, with an average value of 48.3. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability of the seams in the right bank above Elevation 1115 m, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-213 shows the values of the in situ shear strength versus the residual shear strength. All the in situ shear strength values are greater than the residual shear strength values. The smallest difference between the in situ and the residual shear strength is 3 degrees. The minimum measured in situ angle of shearing resistance is 18.5 degrees.

It is prudent to assign an angle of shearing resistance higher than the residual shear strength to this seam. This in situ state factor will be discussed later.

Plates B-216 and B-217 show the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance 11.5 degrees, the representative clay content and liquid limit values for this seam are 50 percent and 45, respectively.

Seams in Upstream Diversion Tunnel Portal

The seams in the upstream diversion tunnel portal were discussed in Section B7.3. Two of these seams were mapped and sampled in great detail. These two seams are Nos. 2 and 3 along the elevation 1080 bench of the upstream diversion tunnel portal and correspond to seams R9 and R8 in the spillway area in the right bank.

An extensive index and direct shear testing program was carried out on the large diameter core samples taken from these seams. In the following section, the results will be discussed.

Seam No. 2

This seam is located within a sequence of alternating, thinly bedded mudrocks at the elevation 1083 m in the upstream diversion tunnel portal. It corresponds to the seam R9 in the spillway area in the right bank. This seam is mostly a single seam type, occasionally a compound seam, with thicknesses ranging from 1 to 40 mm, and averaging 12 mm.

Plates B-218 to B-220 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. Based on the measured values, the representative residual angle of shearing resistance determined for this seam is 11 degrees.

Plate B-221 shows the histogram of the residual angles of shearing resistance measured on samples taken from this seam in the inlet portal. From all the residual angles of shearing resistance measured, 30 percent of them are less than 11 degrees. These are 3 out of 10 results with the measured values of 10.0, 10.6 and 10.9 degrees. The difference between the lowest measured residual angle of shearing resistance (10.0 degrees) and the one assigned for this seam (11 degrees) is one degree. The remaining 70 percent of the results are greater than 11 degrees with a range between 11.3 degrees to 21.3 degrees.

The measured residual shear strength values vary between 10.0 degrees and 21.3 degrees, with a mean value of 13.2 degrees. Plate B-222 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 24 to 53 percent, with an average value of 44.9 percent. The liquid limit values vary between 35.6 to 57.2, with an average value of 47.5. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam No. 2, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-220 shows the values of the in situ shear strength versus the residual shear strength. All the in situ shear strength values are greater than the residual shear strength values. The smallest difference between the in situ and the residual shear strength is one degree. The minimum measured in situ angle of shearing resistance is equal to 16.5 degrees. Hence, assigning a representative residual angle of shearing resistance of 11 degrees to this seam is conservative.

This seam corresponds to the seam R9 in the spillway area which also has a representative residual angle of shearing resistance equal to 11 degrees.

Plates B-223 and B-224 show the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance of 11 degrees, the representative values of the clay content and the liquid limit are 50 percent and 52, respectively.

Seam No. 3

This seam is located at the contact of a sequence of alternating, thinly bedded mudrocks and an underlying, uniform, grey, sheared claystone, at the elevation 1082 m in the upstream division tunnel portal. It corresponds to seam R8 in the spillway area in the right bank. This seam is mostly a single seam type, sometimes a compound seam, with thicknesses ranging from 5 to 80 mm and averaging 37 mm.

Plates B-225 to B-227 show the residual shear strength, the in situ shear strength and the residual versus the in situ shear strength plots. Based on the measured values, the representative residual angle of shearing resistance determined for this seam is 12.5 degrees.

Plate B-228 shows the histogram of the residual angles of shearing resistance measured on samples taken from this seam in the inlet portal. From all the residual angles of shearing resistance measured, 13 percent of them are less than 12.5 degrees. These are 4 out of 32 results with the measured values of 10.3, 11.1, 11.7 and 11.9 degrees. The difference between the lowest measured residual angle of shearing resistance (10.3 degrees) and the one assigned for this seam (12.5 degrees) is 2.2 degrees. The remaining 87 percent of the results are greater than 12.5 degrees with a range between 13 and 23.4 degrees.

The measured residual shear strength values vary between 10.3 degrees and 23.4 degrees, with a mean value of 17.7 degrees. Plate B-229 shows the histogram of the clay content and liquid limit along this seam. The clay content values vary between 27.6 to 64 percent, with an average value of 43.3 percent. The liquid limit values vary between 38 to 56.8, with an average value of 45.8. These variations in the measured angles of shearing resistance, the clay content values and the liquid limit values indicate variability along seam No. 3, which supports assigning a value of the representative residual angle of shearing resistance greater than the measured minimum residual value.

Plate B-227 shows the values of the in situ shear strength versus the residual shear strength. For 3 percent of the results (1 out of 32 results) the in situ shear strength is equal to the residual shear strength. For the remaining 97 percent of the results the in situ shear strength is greater than the residual shear strength. For 3 percent of these results (1 result out of 32 values) the difference between the in situ shear strength and the residual shear strength is 1.5 degrees, and for the remaining of the values, the minimum difference between the in situ shear strength and the residual shear strength is one degree. The minimum measured in situ angle of shearing resistance is 11.7 degrees. Hence, assigning a representative residual angle of shearing resistance of 12.5 degrees to this seam is conservative.

This seam corresponds to the seam R8 in the spillway area which has a representative residual angle of shearing resistance of 12 degrees.

Plates B-230 and B-231 show the residual angle of shearing resistance versus the clay content and liquid limit. For the representative residual angle of shearing resistance of 12.5 degrees, the representative values of the clay content and the liquid limit are 52 percent and 52, respectively. Generally, there are good correlations between the residual angle of shearing resistance, the clay content and the liquid limit. By increasing the clay content or the liquid limit, the residual angle of shearing resistance decreases.

B13.3.3 Summary of Continuous Seams and Their Representative Residual Shear Strengths

As discussed before, the continuous seams in the abutments are R1, R6, R7, R8, R9, R13, R14, R16, R17 and R18. The residual shear strength and index properties of these seams are given in Table B13-2. Also, given in this table are the results for the left bank seams Nos. 2 and 3 at the upstream diversion tunnel portal.

The significance of these seams on the design of different structures and excavated slopes will be discussed in a further section.

TABLE B13-2
CONTINUOUS SEAMS IN ABUTMENT
AND THEIR REPRESENTATIVE RESIDUAL SHEAR STRENGTH

SEAM NO.	REFERENCE ELEVATION AT SPILLWAY CENTRELINE (m)	REPRESENTATIVE LIQUID LIMIT	REPRESENTATIVE CLAY CONTENT (%)	REPRESENTATIVE RESIDUAL ANGLE OF SHEARING RESISTANCE (degrees)
R1	1068.2	54	65	10.5
R6	1084.5	43	49	12.5
R7	1086.5	49	57	12
R8*	1087.5	48	57	12
R8**	1087.5	50	55	12
R9*	1088.5	50	65	11
R9**	1088.5	51	60	11
R13	1096.5	44	50	15
R14	1099.8	45	50	15
R16	1105.0	50	60	12.5
R17	1107.7	47	48	16.0
R18	1115.0	45	50	11.5
UPSTREAM DIVERSION TUNNEL PORTAL				
Seam No. 2	1088.5	52	50	11
Seam No. 3	1087.5	52	52	12.5

NOTES: * Results for R8 and R9 excluding those from Upstream Diversion Tunnel Portal.

** Results for R8 and R9 including those from Upstream Diversion Tunnel Portal.

B13.4 RESIDUAL ANGLE OF SHEARING RESISTANCE VERSUS CLAY CONTENT
AND LIQUID LIMIT

For the continuous seams as given in Tables B13-1 and B13-2, the representative residual angles of shearing resistance were plotted against representative clay content values and representative liquid limit values. These plots are shown on Plates B-232 and B-233.

Also, shown on these Plates are the lower limits defined in Plates B-99 and B-100, where the individual angles of shearing resistance from Mohr plots for each seam at a particular location were plotted against the clay content values and liquid limit values.

The correlation between the representative angles of shearing resistance and the representative clay content and liquid limit values is very good. Generally, by increasing the clay content and the liquid limit, the angle of shearing resistance decreases. Also, the correlation between the "Lower Limit" curves and the results is very good.

B13.5 SHEAR STRENGTH OF SEAMS

B13.5.1 General

In the previous sections, a total of 17 seams were identified for the project. These are V10, V11, V12, V15, V16, V17, V18, R1, R6, R7, R8, R9, R13, R14, R16, R17 and R18. Also, in the previous sections, the representative residual angles of shearing resistance for these seams were discussed. The representative residual angles of shearing

resistance for these seams are given in Tables B13-1 and B13-2. In the following section, the rationale for determining the representative residual shear strength which is based on laboratory testing is presented in relation to the geological components which will be added to this value to obtain the effective angle of shearing resistance for the seams in situ. These geologic components account for the following:

- the geological continuity of the seam,
- the roughness along the seam,
- the thickness of the seam, and
- the in situ state of the seam.

B13.5.2 Representative Residual Shear Strength

The representative residual shear strengths of the seams were discussed in previous sections, and they are given in Tables B13-1 and B13-2. As discussed, the representative residual shear strengths are not the minimum measured along the seams. For a given seam, they have been chosen based on the variability of the shear strength values, the variability being a function of the clay content and the index properties of the infilling in the seams.

Table B13-3 gives the representative shear strength values for the seams. Also, included in this table are the range and mean values for the residual angles of shearing resistance measured along the seams, the difference between the representative angle of shearing resistance and the minimum residual angle of shearing resistance measured, and the percent of measured residual shear strength values that are less than the representative residual shear strength.

It is noted that the representative residual angles of shearing resistance have been selected such that the percent of the measured values of the angle of shearing resistance less than the representative residual shear strength, is usually between 15 and 35. This number varied according to the difference between the minimum measured residual shear strength and the representative residual angles of shearing resistance.

For the cases where the difference between the minimum measured ϕ'_r and the representative ϕ'_r was large, then a lower representative value of ϕ'_r was adopted which resulted in a smaller percent of ϕ'_r values being smaller than representative ϕ'_r . These seams are V18 and R1. For seam V18, the difference between minimum ϕ'_r and the representative ϕ'_r is equal to 3 degrees and the percent of ϕ'_r values less than the representative ϕ'_r is 30 percent. For the seam R1, the difference between minimum ϕ'_r and the representative ϕ'_r is equal to 1.8 degrees and the percent of ϕ'_r values less than the representative ϕ'_r is 14 percent. However, in the case of the seam R9, the percent of ϕ'_r values less than the representative ϕ'_r is 35 percent and the difference between the minimum measured ϕ'_r and the representative ϕ'_r is 2.7 degrees. The reason is that, there is only one ϕ'_r value at 8.3 degrees and the next lowest value 9.9 degrees which results in a difference between this value and the representative ϕ'_r value of 1.1 degrees.

TABLE B13-3
CONTINUOUS SEAMS
REPRESENTATIVE RESIDUAL ANGLES OF SHEARING RESISTANCE

DESIGN SEAM NO.	ELEVATION (m)	$\phi'r$ REPRESENT- ATIVE (degrees)	$\phi'r$ RANGE (degrees)	$\phi'r$ MEAN (degrees)	$\phi'r$ REPRESENT- ATIVE - $\phi'r$ MIN. (degrees)	$\phi'r$ LESS THAN $\phi'r$ REPRESENT- ATIVE (%)
<u>SEAMS IN VALLEY BOTTOM</u>						
V10	1025.6	13.5	13.0-25.2	17.4	0.5	25
V11	1027.6	14.5	14.4-19.3	16.4	0.1	25
V12	1030.7	12	10.9-29.4	20.2	1.1	20
V15	1043.9	22.5	22.4-29.8	25.7	0.1	20
V16	1046.8	15.5	14.5-26.0	18.3	1.0	32
V17	1047.7	21.0	20.5-29.7	26.1	0.5	17
V18	1049.4	15.0	12.0-23.7	16.6	3.0	30
<u>SEAMS IN ABUTMENTS</u>						
R1	1068.5	10.5	8.7-14.7	11.6	1.8	14
R6	1084.5	12.5	12.3-15.8	13.9	0.2	33
R7	1086.5	12	11.9-12.8	12.2	0.1	50
R8	1087.5	12	10.3-23.4	16.8	1.7	12
R9	1088.5	11	8.3-21.3	12.4	2.7	35
R13	1096.5	15	13.5-18.3	16.3	1.5	25
R14	1100	15	14.3-18.4	15.6	0.7	43
R16	1105.0	12.5	10.8-24.9	14.9	1.7	33
R17	1107.7	16.0	15.6-17.4	16.2	0.4	50
R18	1115	11.5	9.9-22.5	14.1	1.6	33

For the cases where the difference between the minimum measured $\phi'r$ and the representative $\phi'r$ was small, then a higher representative value of $\phi'r$ was adopted which resulted in a higher percent of $\phi'r$ values smaller than representative $\phi'r$. These seams are R6, R7 and R17. For seam R6, the difference between minimum $\phi'r$ and the representative $\phi'r$ is equal to 0.2 degrees and the percent of $\phi'r$ values less than the representative $\phi'r$ is 33 percent. For seam R7, the difference between minimum $\phi'r$ and the representative $\phi'r$ is equal to 0.1 degrees and the percentage of $\phi'r$ values less than the representative $\phi'r$ is 50 percent. For the seam R17, the difference between minimum $\phi'r$ and the representative $\phi'r$ is equal to 0.4 degrees and the percentage of $\phi'r$ values less than the representative $\phi'r$ is 50 percent.

As discussed, the residual shear strength, clay content and liquid limit values vary along all the seams. For some of the seams, this variation is small and for some it is high. Based on these variations, it was concluded that the representative value of the residual shear strength for a given seam should not be equal to the lowest measured value of the residual angle of shearing resistance along that seam. It is considered realistic to use a representative residual angle of shearing resistance along a given seam somewhat higher than the minimum measured $\phi'r$ value.

B13.5.3 Geological Continuity

The geological continuity of the seams was discussed in Section B10.0. The seams have been categorized as continuous or discontinuous. The continuous seams that are being considered in the design are those which extend for lengths equal or greater to the dimensions of the various structures or portions of structures. All the continuous seams have been discussed in previous sections.

The discontinuous seams will mobilize higher shear strength due to the contribution of the unsheared claystone shear strength, hence they have not been considered in the analyses.

B13.5.4 Roughness Component

As discussed previously, the roughness component contributes to the total design shear strength. Seam roughness has been assessed over base lengths which are considered long enough to be representative of the geometry of the seams. The measured values are thus appropriate for the determination of the shear strength of the foundation of the project structures. An average of 0.5° has been estimated as a representative roughness of all seams.

In reality, while it is most applicable to the thicker seams, it is probably somewhat conservative for the thinner seams where the real seam roughness could be slightly greater.

It is noted that the wall rock roughness may exceed the seam roughness, but that wall rock roughness is not appropriate for the design shear strength determination. Wall rock roughness is, however, contributory to the thickness shear strength factor which is discussed following.

The present seam roughness of 0.5° is less than the 1.5° value estimated in the preliminary studies in 1985. This is essentially due to a better understanding of the nature of the seams at the Oldman site, as more detailed data were collected during the continuing design studies.

B13.5.5 Seam Thickness

In Section B9.0, the seams were categorized as thick and thin. The thickness of the seam affects the amount of the mobilized shear strength along the seam. As discussed in Section B11.0, for the thick seams the effect of thickness on the shear strength is zero. However, for the thin seams, where the thickness is less than 2 mm, the mobilized shear strength will be higher than the representative residual shear strength. This is due to the effect of wall rock roughness and also the limited space available for the full development of the shear zones which results in the interference from the adjacent rock. The strong rock will compress the shear zone into the weaker material within the seam, and it will cause a redistribution of the stresses and development of a different shear zone pattern.

The conclusion made in Section B11.0 is that for thick seams there is no additional shear strength and for thin seams, the effect of thickness is to increase the shear strength by 0.5 degrees. Table B13-4 gives the thickness effect component which has to be added to the angle to shearing resistance.

TABLE B13-4
CONTINUOUS SEAMS,
SEAM THICKNESS EFFECT

DESIGN SEAM NO.	ELEVATION (m)	θ' r REPRESENTATIVE (degrees)	SEAM ASSESSMENT	THICKNESS COMPONENT (degrees)
<u>SEAMS IN VALLEY BOTTOM</u>				
V10	1025.6	13.5	Thick	0
V11	1027.6	14.5	Thick	0
V12	1030.7	12.0	Thick	0
V15	1043.9	22.5	Thick	0
V16	1046.8	15.5	Thin	0.5
V17	1047.7	21.0	Thick	0
V18	1049.4	15.0	Thin	0.5
<u>SEAMS IN ABUTMENTS</u>				
R1	1068.2	10.5	Thick	0
R6	1084.5	12.5	Thick	0
R7	1086.5	12	Thin	0.5
R8	1087.5	12	Thick	0
R9	1088.5	11	Thick	0
R13	1096.5	15	Thick	0
R14	1099.8	15	Thick	0
R16	1105	12.5	Thick	0
R17	1107.7	16.0	Thick	0
R18	1115	11.5	Thick	0

B13.5.6 In Situ State Effect

For some of the seams, the measured in situ angle of shearing resistance is greater than the measured residual angle of shearing resistance.

Table B13-5 gives the continuous seams, the representative residual angle of shearing resistance, the percentage of the measured in situ values being at the residual state, the range of measured values of the in situ angle of shearing resistance, the minimum difference between the in situ and residual angles of shearing resistance, and in situ state effect component which has to be added to the angle of shearing resistance. In comparing the measured in situ and residual angles of shearing resistance, only the results from large diameter core samples were considered.

For some of the seams, there was not a single in situ shear strength to be equal to the residual shear strength. For these seams, assuming that the entire seam is at the residual state is conservative. Hence, it was concluded that for the seams where all the in situ angles of shearing resistance are higher than the residual angles of shearing resistance, an "in situ state" component equal to 0.5 degrees should be added to the representative angle of shearing resistance. For the remaining seams where the percentage of the points at the residual state are not equal to zero, this in situ state component is equal to zero.

The in situ state component of 0.5 degrees is a conservative value. However, based on the consideration that the shear surface developed in the direct shear test may be different from the one already existing in the ground, it was decided to use a conservative value.

TABLE B13-5
CONTINUOUS SEAMS
RESIDUAL AND IN SITU ANGLES OF SHEARING RESISTANCE

DESIGN SEAM NO.	ELEVATION (m)	$\phi'r$ REPRESENTATIVE (degrees)	$\phi'r = \phi$ IN SITU LARGE DIAMETER CORE SAMPLES ONLY (%)	RANGE ϕ IN SITU LARGE DIAMETER CORE SAMPLES ONLY (degrees)	ϕ IN SITU $-\phi'r$ MINIMUM (degrees)	IN SITU STATE COMPONENT (degrees)
<u>SEAMS IN VALLEY BOTTOM</u>						
V10	1025.6	13.5	0	15.6-17.2	0.7	0.5
V11	1027.6	14.5	0	21.3-26.1	5.5	0.5
V12	1030.7	12.0	60	10.9-18.5	0.0	0
V15	1043.9	22.5	N/A	N/A	11.4	0
V16	1046.8	15.5	0	23.2-33.2	3.7	0.5
V17	1047.7	21.0	N/A	N/A	35.2	0
V18	1049.4	15.0	30	12.7-29.0	0.0	0
<u>SEAMS IN ABUTMENTS</u>						
R1	1068.2	10.5	0	15.1-21.2	2.4	0.5
R6	1084.5	12.5	0	19.3-28.4	6.5	0.5
R7	1086.5	12	N/A	N/A	13.7	0
R8	1087.5	12	3	11.7-38.3	0	0
R9	1088.5	11	31	8.3-33.3	0	0
R13	1096.5	15	33	15.9-21.7	0	0
R14	1099.8	15	0	17.8-23.4	1.7	0.5
R16	1105	12.5	8	12.1-29.7	0	0
R17	1107.7	16.0	100	17.4	0	0
R18	1115	11.5	0	18.3-26.0	3.6	0.5

B13.5.7 Effective Shear Strength of Seams

The effective angle of shearing resistance of the seam is equal to the representative angle of shearing resistance plus the roughness, thickness and in situ state components.

For all the seams, the effective cohesion along the seam is equal to zero.

The seams, their index properties and the values of the shear strength contribution due to roughness, thickness and in situ state and effective angles of shearing resistance are given in Table B13-6 for both the valley bottom and abutments.

B13.6 DESIGN SEAMS

In this section, the design seams in the valley bottom and in the abutments are discussed.

B13.6.1 Design Seams in Valley Bottom

Table B13-6 lists the continuous seams that are considered to be of significance to the design and shows their engineering properties.

TABLE B13-6
CONTINUOUS SEAMS
EFFECTIVE ANGLE OF SHEARING RESISTANCE

DESIGN SEAM NO.	ELEVATION (m)	ϕ' REPRESENT- ATIVE (degrees)	LL	C (%)	ROUGHNESS COMPONENT (degrees)	THICKNESS COMPONENT (degrees)	IN SITU STATE COMPONENT (degrees)	EFFECTIVE ANGLE OF SHEARING RESISTANCE (degrees)
<u>SEAMS IN VALLEY BOTTOM</u>								
V10	1025.6	13.5	40	37	0.5	0	0.5	14.5
V11	1027.6	14.5	34	36	0.5	0	0.5	15.5
V12	1030.7	12.0	42	51	0.5	0	0	12.5
V15	1043.9	22.5	36	40	0.5	0	0	23.0
V16	1046.8	15.5	41	39	0.5	0.5	0.5	17.0
V17	1047.7	21.0	30	18	0.5	0	0	21.5
V18	1049.4	15.0	36	42	0.5	0.5	0	16.0
<u>SEAMS IN ABUTMENTS</u>								
R1	1068.2	10.5	54	65	0.5	0	0.5	11.5
R6	1084.5	12.5	43	49	0.5	0	0.5	13.5
R7	1086.5	12	49	57	0.5	0.5	0	13.0
R8	1087.5	12	50	55	0.5	0	0	12.5
R9	1088.5	11	51	60	0.5	0	0	11.5
R13	1096.5	15	44	50	0.5	0	0	15.5
R14	1100	15	45	50	0.5	0	0.5	16.0
R16	1105	12.5	50	60	0.5	0	0	13.0
R17	1107.7	16.0	47	48	0.5	0	0	16.5
R18	1115	11.5	45	50	0.5	0	0.5	12.5

Seams V10 to V12 are located in the mudrock sequence within the Basal Sandstone. Seam V12, the uppermost seam within this group, has the lowest shear strength. Hence, for the design of the dam, seam V12 is more critical than seams V10 and V11. However, as shown on Table B10-4, seam V12 is only continuous for the upstream section of the dam. In the downstream section, this seam is apparently discontinuous and seam V11 becomes the significant seam. The design of the dam, has been based on the assumption that seam V12 is continuous in the foundation of both upstream and downstream sections of the dam.

Seams V15 to V17 are located in the upper claystone layer overlying the Basal Sandstone. As discussed, in the downstream section of the dam, this upper claystone layer has been replaced by channel sandstone for almost 70 percent of the foundation of the dam. Hence, seams V15 to V17 do not control the downstream foundation of the dam. They are however continuous in the upstream foundation of the dam.

Of the group of seams V15 to V17, only seam V16 has been considered as a design seam for the dam, as it has the lowest shear strength.

Although seam V16 is not present in the 70 percent of the downstream foundation of the dam the stability analyses of the dam included a case where it was assumed to be continuous, to investigate its influence on dam stability .

The top of bedrock is at elevation 1048 m approximately and so seam V18 is not present in the foundation of the dam in river valley. Seam V18 is a design seam for the river slopes and the abutment section of the dam.

Seam V20, located 2 m above seam V18, is continuous in the valley slopes. However, seam V20 has not been considered as the critical seam controlling the design of a slope is V18 as it passes through the toe of the valley slopes.

In summary the design seams in the valley bottom are V12, V16 and V18, these are shown on Plates B-32 to B-35. Their shear strength is discussed in the Section B13.7.

B13.6.2 Design Seams in Abutments

There are 18 seams in the abutments (R1 to R18). As discussed in the previous sections, seams R2, R3, R4, R5, R11 and R12 are discontinuous, and have not been considered in the design. Seam R10 is not present at the foundation of the spillway headworks structure, and in other locations it merges with seam R9, hence seam R10 has also not been considered. The remaining seams are continuous. Table B13-6 lists these continuous seams and their engineering properties.

The design seams in the abutments are R1, R6, R7, R8, R9, R13, R14, R15, R16, R17 and R18. These seams are shown on Plates B-32 to B-35.

Seam R10 is discontinuous in the area influenced by the spillway headworks structure and has not been considered in the design. For seam R15, the shear strength of seam R16 has been used.

Seams R1, R6, R7 and R8 are important for the design of the existing slopes in the river valley and the excavated slopes in the spillway chute. Seams R9, R13 and R14 are important in the design of the existing slopes in the river valley, the excavated slopes in the spillway chute and the spillway headworks structure. Seams R14, R15, R16, R17 and R18 are important in the design of the excavated slopes in the spillway approach channel.

B13.6.3 Summary of Design Seams and Their Shear Strengths

From the total of 39 seams assessed in the project site, 13 seams have been considered to be significant in the design of the dam, the the excavated and existing slopes, the spillway and the relevant structures. These 13 seams and their design effective angles of shearing resistance are given in Table B13-7. The design effective angle of shearing resistance is equal to the representative angle of shearing resistance plus roughness component, plus thickness component and plus in situ state component. As mentioned before, for seam R15 the shear strength of seam R16 has been used.

The design seams and their angles of shearing resistance are schematically shown on Plates B-32 to B-35.

TABLE B13-7
DESIGN SEAMS

DESIGN SEAM NO.	ELEVATION (m)	ϕ' REPRESENT- ATIVE (degrees)	LL	C (%)	ROUGHNESS COMPONENT (degrees)	THICKNESS COMPONENT (degrees)	IN SITU STATE COMPONENT (degrees)	DESIGN EFFECTIVE ANGLE OF SHEARING RESISTANCE (degrees)
<u>SEAMS IN VALLEY BOTTOM</u>								
V12	1030.7	12.0	42	51	0.5	0	0	12.5
V16	1046.8	15.5	41	39	0.5	0.5	0.5	17.0
V18	1049.4	15.0	36	42	0.5	0.5	0	16.0
<u>SEAMS IN ABUTMENTS</u>								
R1	1068.2	10.5	54	65	0.5	0	0.5	11.5
R6	1084.5	12.5	43	49	0.5	0	0.5	13.5
R7	1086.5	12	49	57	0.5	0.5	0	13.0
R8	1087.5	12	50	55	0.5	0	0	12.5
R9	1088.5	11	51	60	0.5	0	0	11.5
R13	1096.5	15	44	50	0.5	0	0	15.5
R14	1100	15	45	50	0.5	0	0.5	16.0
R16	1105	12.5	50	60	0.5	0	0	13.0
R17	1107.7	16.0	47	48	0.5	0	0	16.5
R18	1115	11.5	45	50	0.5	0	0.5	12.5



B14.0 BEDDING PLANE SHEAR STRENGTH

Between the continuous seams, an effective angle of shearing resistance of 17.5 degrees along planes parallel to the bedding has been used for the design, except where there is overwhelming evidence that the rock is massive sandstone. There is a significantly weaker zone between elevation 1085 to 1090 m where an effective angle of shearing resistance of 14 degrees has been used. This basis for design has been used at all elevations except where the major design seams apply (Table B14-1). The design shear strength has been obtained by adding 1.5 degrees to the representative residual angle of shearing resistance.

TABLE B14-1
BEDDING PLANE SHEAR STRENGTH BETWEEN MAJOR DESIGN SEAMS

ELEVATIONS (m)	REPRESENTATIVE RESIDUAL ANGLE OF SHEARING RESISTANCE	GEOLOGICAL COMPONENT	DESIGN EFFECTIVE ANGLE OF SHEARING RESISTANCE
Below El. 1040	16°	1.5°	17.5°
El. 1040 to El. 1050	16°	1.5°	17.5°
El. 1050 to El. 1085	16°	1.5°	17.5°
El. 1085 to El. 1090	12.5°	1.5°	14°
El. 1090 to El. 1100	16°	1.5°	17.5°
Above El. 1100	16°	1.5°	17.5°

B15.0 CROSS BEDDING SHEAR STRENGTH

B15.1 CROSS BEDDING SHEAR STRENGTH OF SANDSTONE

The sandstone units contain several combinations of horizontal and vertical joints as discussed in the Preliminary Report (UMA/Acres (1986)). The cross bedding shear strength assigned to sandstone units is:

Effective angle of shearing resistance $\phi' = 60^\circ$

Effective cohesion $c' = 0$

The effective cohesion was assumed to be zero to be consistent with vertical joints that are found in all sandstone units.

B15.2 CROSS BEDDING SHEAR STRENGTH OF MUDROCK

An effective angle of shearing resistance of 35° was assigned to the cross bedding shear strength of all mudrock units. The effective cohesion in cross bedding was varied to reflect the degree of weathering and stress relief, and to account for the relative amount of siltstone and claystone in the unit. A higher effective cohesion was used as the claystone content increased.

For the weathered, brecciated, slickensided and highly fractured mudrock layers, the effective cohesion in cross bedding was taken to be zero.

For the unweathered intact mudrock, the effective cohesion in cross bedding shear was assumed as 200 kPa. For the slightly weathered mudrocks, a cross bedding effective cohesion between 0 and 200 kPa was selected based on the drillhole data.

In the foundation of the dam the cross bedding effective cohesion was assumed to be equal to zero.

B16.0 CYCLIC SHEAR STRENGTH

Static and dynamic finite element analyses were performed on the Oldman River Dam to determine the stability of the structure for static and earthquake dynamic loadings.

On the first phase, a static stress analysis was conducted for the dam cross-section to determine the stress and strain distributions with particular emphasis placed on behavior of the seams in the foundation bedrock. This analysis provided an initial estimate of the static stress distribution and anticipated material deformation characteristics. This provides a more accurate tool to assess the stability of the dam and develops the initial stress distribution to be input to the dynamic stress analysis.

The second phase of the study involved the analysis of dynamic stresses and displacements developed in the dam when subjected to the design earthquake accelerations. The stresses were compared to available material strengths and the displacements compared to allowable maximum deformations to assess the dynamic factor of safety.

B16.1 MATERIAL PROPERTIES USED IN STATIC FINITE ELEMENT ANALYSIS

The simplified dam section was defined using seven distinct material types. The shear strength and deformation material laws input to the model were estimated from laboratory triaxial and direct shear tests conducted on compacted and undisturbed samples obtained from the dam site and from data presented in the literature. The seven soil units used to represent the dam section are as follows:

1. Compacted Glacial Till Core

The core of the dam consists of compacted silty clay till obtained from borrow areas at the dam site. Consolidated undrained triaxial tests with pore pressure measurements were conducted on compacted samples. They provided estimates of the initial Young's modulus (E_i), Poisson's ratio (ν), effective shear strength parameters (c' , ϕ'), and the nonlinear stress-strain relationship. Table B16-1 illustrates the values used in static stress analysis.

2. Compacted Granular and Random Fill Shell Material

The material comprising the shells of the dam consists of compacted granular and random fill. Material properties for this unit were selected from results published in the literature for similar materials and are tabulated in Table B16-1. The filter zones adjacent to the central core are included within the shell zone because of the similarity of the two materials.

3. Foundation Alluvium and Colluvium

The river valley deposits consist of a substantial quantity of colluvium material overlying the alluvial river granular deposits. Complete excavation of the colluvium is planned for areas beneath the dam shells. A layer of this material was included beneath the dam shells for the finite element analysis in order to evaluate the liquefaction potential. The material properties used in the analysis were estimated from values presented in the literature.

4&5 Seams Within Foundation Bedrock

Drill hole, shaft and test tunnel data indicated the presence of continuous sub-horizontal seams within the foundation bedrock. The representative residual shearing strength plus the roughness, thickness and in situ state factors was used for these seams. The residual angle of shearing resistance used in the analysis has been obtained from conventional and large diameter direct shear tests. These seams are modelled as thin continuous horizontal layers located within the bedrock units.

6&7 Intact Mudrock and Sandstone Units

The upper mudrock unit is modelled as a thin continuous horizontal layer in the foundation. The sandstone unit directly underlies the mudrock layer. Material deformation properties were obtained from laboratory triaxial testing data. The intact bedrock units were modelled as linear-elastic materials since the shear stresses developed from static loading do not approach the available strength of these units.

TABLE B16-1
MATERIAL PROPERTIES USED IN STATIC ANALYSIS

MATERIAL	c' (kPa)	ϕ' (Deg.)	γ (kN/m ³)	ν	E_1 (MPa)
1. Compacted Till (Core)	0	25	19.6	0.4	20 + 67 (σ'_m)
2. Compacted Granular (Shells)	0	35	21.6	0.3	84 + 267 (σ'_m)
3. Colluvium/Alluvium (Foundation)	0	28	21.6	0.3	84 + 267 (σ'_m)
4. Seam in Mudrock (Foundation)	0	17.5	23.6	0.4	400
5. Seam in Sandstone (Foundation)	0	12	23.6	0.3	400
6. Intact Mudrock (Foundation)	-	Linear	23.6	0.4	2,000
7. Intact Sandstone (Foundation)	-	Linear	23.6	0.3	17,000

$$\sigma'_m = \text{mean effective stress} = (\sigma'_1 + \sigma'_3)/2$$

B16.2 MATERIAL PROPERTIES USED IN DYNAMIC RESPONSE ANALYSIS

A total of seven material units were used to define the dam cross-section. Material properties were input in the form of initial shear modulus for small strains (G_{max}) and Poisson's ratio (ν). The finite element program used incorporates a material algorithm which modifies the shear modulus and damping ratio for each element to be compatible with the shear strain developed within the element in response to the earthquake load.

Table B16-2 lists the initial shear modulus (G) and the Poisson's ratio (ν) values input to the model as function of initial effective confining pressure:

$$\sigma'_m = \frac{(1 + 2 K_0) \sigma'_v}{3} \approx \frac{\sigma'_1 + \sigma'_3}{2}$$

With the exception of the bedrock units, all materials were assigned initial shear modulus values based upon the recommendations of Seed and Idriss (1970) since no site specific laboratory cyclic test data was available at the time of the study. Initial shear modulus was developed from the following expression:

$$G_{max} = 1000 (K_2)_{max} (\sigma'_m)^{1/2}$$

where G_{max} = initial shear modulus corresponding to small strains, (KSF)

$(K_2)_{max}$ = dimensionless factor depending upon material characteristics (Seed and Idriss (1970))

σ'_m = effective mean principal stress (from static analysis), (PSF)

The material properties for the bedrock units were estimated from static triaxial and direct shear box laboratory tests.

Cyclic laboratory tests results indicated that there are no losses in the strength of compacted till and in the residual angle of shearing resistance of the seams under dynamic earthquake loading.

TABLE B16-2
INITIAL MATERIAL PROPERTIES INPUT TO DYNAMIC ANALYSIS

MATERIAL	UNIT WEIGHT (PCF)	K ₂	CONSTANT G _{max} (KSF)	✓
1. Compacted Till (Core)	125	50	----	0.4
2. Compacted Granular (Shells)	137	75	----	0.3
3. Colluvium/Alluvium (Foundation)	137	40	----	0.3
4. Seam in Mudrock (Foundation)	150	50	----	0.4
5. Seam in Sandstone (Foundation)	150	50	----	0.4
6. Intact Mudrock (Foundation)	150	--	13,900	0.4
7. Intact Sandstone (Foundation)	150	--	118,000	0.3

B17.0 CYCLIC SHEAR STRENGTH TESTING

The following section details the laboratory testing and interpretation methods used in the evaluation of the dynamic shearing behavior of three different materials incorporated in the earth dam and the foundation bedrock. These materials are:

- i) compacted silty clay till representing the material in the dam core;
- ii) reconstituted samples of potentially liquefiable, surficial alluvial silty sand located in the foundation beneath the dam shell zones; and
- iii) undisturbed bedrock samples containing clay seams found within the claystone bedrock existing in the dam foundation.

This section of the report represents a summary of the Dynamic Strength Laboratory Testing Program compiled by EBA Engineering Consultants Ltd. (UMA-Acres (1987)).

B17.1 TESTING PROGRAM FOR COMPACTED TILL SAMPLES

A triaxial test program was conducted on compacted silty clay till samples representing the material proposed for use in the construction of the dam core. The testing program comprised 8 static triaxial compression tests, and 6 cyclic triaxial compression tests in which the samples were sheared to failure following cycling. The test types and principal variables are summarized in Table B17-1.

TABLE B17-1
TEST PROGRAM - COMPACTED TILL

TEST NUMBER	TEST TYPE	CONSOLIDATION PROCEDURE (SEE TEXT)	LATERAL CONSOLIDATION STRESS (kPa)	Kc
CAU-1	CAU Static	A	300	0.67
CAU-1A	CAU Static	B	300	0.67
CAU-3	CAU Static	A	600	0.67
CAU-3A	CAU Static	B	600	0.67
CAU-5	CAU Static	A	1000	0.67
CAU-5A	CAU Static	B	1000	0.67
CU-7	CIU Static	C	500	1.00
CU-9	CIU Static	C	1000	1.00
CAU-2	CAU Cyclic	B	300	0.67
CAU-4	CAU Cyclic	B	600	0.67
CAU-6	CAU Cyclic	B	1000	0.67
CU-8	CIU Cyclic	C	500	1.00
CU-8A	CIU Cyclic	C	500	1.00
CU-10	CIU Cyclic	C	1000	1.00

B17.1.1 Test Procedures

a) Sample Preparation

The samples were reconstituted from silty clay till material obtained from drillhole AH-85-B67, Sample ES19. Atterberg Limits were conducted on these samples and this material was found to have a liquid limit of 33 and a plastic limit of 14. The material was compacted in a Standard Proctor mold to 100 percent of the maximum dry density at optimum moisture content. A 60 mm nominal diameter sample was then trimmed from the compacted sample, and set up in the triaxial cell, in a conventional manner.

b) Testing Procedures, Static Triaxial Tests

Consolidation pressures were applied in three different ways, as noted on Table B17-1. In all cases, an isotropic stress equal to the desired value of the lateral consolidation stress was applied. The sample was allowed to consolidate, with measurement of pore fluid expulsion, until primary consolidation ceased. This stage was immediately followed by shearing in tests 7 and 9 (method C).

For anisotropically consolidated tests, the anisotropic stress increment was imposed in two ways. In method A (tests 1, 3 and 5) a deviator stress was imposed at a constant rate of axial deformation until the desired stress conditions were reached. The stress increment was imposed under drained conditions, at a rate determined from the isotropic consolidation stage to ensure full drainage. Undrained shearing commenced at a constant rate of axial deformation, immediately after the desired consolidation stress had been reached.

It was suspected that residual pore pressures remained following "consolidation" by the above method, and a parallel series of tests (1A, 3A and 5A) was performed using method B. This involved incremental application of the deviator stress using dead loads, and allowing drainage under each load increment until primary consolidation had ceased. Following full consolidation under the desired stress conditions, undrained shearing commenced at constant rate of axial deformation.

In all tests, measurements were made of axial strain, deviator stress and pore pressure during undrained shearing.

c) Testing Procedures, Cyclic Triaxial Tests

Anisotropic consolidation for cyclic tests 2, 4 and 6 was carried out using method B as described above for the static tests. Following full primary consolidation under the desired stress conditions, the loading ram was locked in position and the triaxial cell was transferred to the cyclic loading frame. The means of application of the cyclic deviator stress was a Bellofram air cylinder connected through two parallel pressure regulating valves to a compressed nitrogen supply. An electronically controlled solenoid valve switched between the two pressure valves in order to provide an alternating high and low pressure to the Bellofram.

Ten cycles of a predetermined deviator stress were applied to the sample, undrained, and cyclic axial stress, axial strain and pore pressure were recorded automatically during the cycling process. Following cycling, the test was returned to the deformation controlled loading frame and sheared undrained to failure. Pore pressures induced during cycling were allowed to dissipate in tests 2 and 4 prior to the undrained shearing phase.

Isotropic consolidation for tests 8, 8A and 10 was conducted in one stage under the prescribed cell pressure (method C). Following completion of primary consolidation, the triaxial cell was transferred to the cyclic loading frame and the sample was subjected to 10 undrained cycles of a predetermined deviator stress.

Immediately after cycling (tests 8 and 10) the sample was sheared, undrained, in the deformation controlled loading frame. Since it was suspected that pore pressures within the sample were not uniform following cycling, test 8A was carried out in which post-cyclic pore pressures were allowed to equalize, though not dissipate.

Axial stress, axial strain and pore pressure were recorded during the static and cyclic stages of all tests.

B17.2 TESTING PROGRAM FOR SURFICIAL SAND ALLUVIUM

A triaxial test program was conducted on reconstituted samples of potentially liquefiable alluvial sand present as a surficial deposit in the river valley. This material is located in the foundation beneath the location of the shells of the dam structure and the following laboratory testing program was conducted to define the dynamic shearing behavior of this material to determine the potential for liquefaction under cyclic loading.

The testing program comprised 7 static triaxial compression tests, and 11 cyclic triaxial compression tests. The test types and the principal variables are summarized in Table B17-2.

TABLE B17-2
TEST PROGRAM - SAND ALLUVIUM

TEST NUMBER	TEST TYPE	LATERAL CONSOLIDATION STRESS (kPa)	VERTICAL CONSOLIDATION STRESS (kPa)	PRE-SHEAR VOID RATIO	RELATIVE DENSITY(%)
CAU-11	CAU Static	600	900	0.477	83
CAU-12	CAU Cyclic	600	900	0.460	86
CAU-13	CAU Cyclic	600	900	0.495	80
CAU-14	CAU Static	600	900	0.526	74
CAU-14a	CAU Static	600	900	0.525	74
CAU-15	CAU Cyclic	600	900	0.534	73
CAU-16	CAU Cyclic	600	900	0.523	75
CAU-17	CAU Static	600	900	0.541	72
CAU-18	CAU Cyclic	600	900	0.537	72
CAU-19	CAU Static	200	300	0.655	51
CAU-20	CAU Cyclic	200	300	0.613	59
CAU-21	CAU Cyclic	200	300	0.612	59
CAU-22	CAU Static	600	900	0.483	82
CAU-23	CAU Cyclic	600	900	0.448	88
CAU-24*	CAU Cyclic	200	300	0.609	59
CAU-25	CAU Cyclic	200	300	0.630	56
CAU-26	CAU Cyclic	200	300	0.598	62
CAU-27	CAU Cyclic	200	300	0.553	70
CAU-28	CAU Cyclic	200	300	0.546	71
CAU-29	CAU Cyclic	200	300	0.554	69

* Note: Test not completed due to equipment malfunction

Test Procedures

a) Classification and Density Testing

Prior to triaxial testing, 22 particle size distribution tests were conducted on samples of the sand alluvium material. Based on these tests, a single sample from Trench BT-86-D335 Level F, Sample 12 was chosen as it best represented the average gradation of the alluvium materials.

The above mentioned sample was then subjected to determinations of specific gravity and maximum/minimum density. Specific gravity testing yielded a specific gravity of 2.626 using the procedure specified in ASTM Designation D854. The maximum density was determined in accordance with ASTM designation D4253-83 and yielded a maximum density of 1.905 Mg/m³. The minimum density was determined using a modified method known as the Kolbuzewski method. This method involves depositing a known weight of dry material into a 2 litre graduated cylinder from a funnel at a certain rate. In past testing, this method has shown lower densities than those typically obtained using the ASTM procedure and as such is believed to better determine the minimum density. Using this method, a minimum density of 1.352 Mg/m³ was determined for the sample used to construct the triaxial test specimens. These values of maximum and minimum density have been used in the calculation of the relative densities of the test specimens as shown in Table B17-2.

b) Testing Procedures, Static Triaxial Tests

1) Sample Preparation

The material was compacted with varying compactive effort and at various water contents into a membrane lined, split-walled specimen former set up on the triaxial cell base pedestal. The moisture content and the compactive effort were varied in order to achieve varying void ratios prior to testing.

After the specimen had been formed and enclosed in the membrane, water was flushed upward through it until water was observed at the top of the specimen. At this time the top cap was installed, a slight vacuum was applied to the specimen to avoid collapse, and the triaxial cell was assembled and filled with water. The specimen was then back-pressure saturated by increasing both the cell pressure and the internal pore pressure in increments while maintaining a small positive effective pore pressure until the specimen was shown to exist in a saturated state by performing "B tests". The specimen was assumed to be saturated if a "B" value of 0.95 or greater was determined from the saturation test.

ii) Test Procedures

All of the triaxial tests were conducted on specimens that had been anisotropically consolidated. They were either consolidated with lateral consolidation stresses of 200 kPa and vertical consolidation stresses of 300 kPa or lateral stresses of 600 kPa and vertical stresses of 900 kPa. The all-around confining stress was first applied in increments until the confining stress equaled that of the lateral stress at which the test would be conducted. These incremental stresses were maintained and the quantity of pore fluid expelled from the sample was monitored until the primary consolidation had ceased, at which time the next increment was applied. After consolidation from the final lateral consolidation stress had ceased the vertical consolidation stress was increased by applying a deviator stress

to the specimen under drained conditions until the desired stress was reached. This stress was increased at a rate determined from the isotropic consolidation stage previously completed, such that full drainage was occurring. Undrained shearing then commenced at a constant rate of axial deformation, immediately after the desired consolidation stress had been reached.

c) Testing Procedures, Cyclic Triaxial Tests

i) Sample Preparation.

All of the specimens that were subjected to cyclic testing were saturated and consolidated following the same procedure as discussed for the static triaxial tests.

ii) Test Procedures

Following full primary consolidation under the desired stress conditions, the loading ram was locked into position and the triaxial cell was transferred to the cyclic loading frame. The means of application of the cyclic deviator stress was a Bellofram air cylinder connected through two parallel pressure regulating valves to compressed nitrogen supply. An electronically controlled solenoid valve switched between the two pressure valves in order to provide an alternating high and low pressure to the Bellofram.

Varying numbers of cycles of predetermined deviator stresses were applied in an undrained manner to the specimen, the objective being to determine the number of cycles required to cause failure for each stress level. Cyclic axial stress, axial strain, and pore pressure were recorded automatically during the cycling process. Most of the tests used several varying levels of cyclic deviator stresses with generally a maximum of 1000 cycles being applied to bring the specimen to failure. Specimen failure was interpreted to be occurring when the amounts of strain occurring during subsequent cycles was observed to be accelerating.

d) Pre-Shear Void Ratio Determination

Because of the tendency for specimens prepared at low densities to densify during the saturation phase of sample preparation, a method of determining the density of the specimen prior to shearing was needed. It is normal practice during triaxial testing to make the assumption that no volume change occurs during the saturation phase and base the preshear void ratio simply on the measured sample volume minus the volume change that occurs during consolidation. Because the void ratios specified for testing were quite low, there was found to be substantial densification (collapse) of the specimens during saturation. The densification was, in fact, so severe that the change in volume of the specimen was visible to the naked eye. Using the normally accepted procedure of void ratio calculation based on densification occurring only during consolidation would have yielded erroneous values of pre-shear void ratio.

Specimen collapse occurs in these specimens because the very low initial densities rely on surface tension of the water present in the material to maintain the structure. When the specimen is then flooded with water this surface tension is destroyed and the specimens have a tendency to collapse.

The specimens for test numbers CAU11-CAU17 were prepared as described above, that is, the material was reconstituted in a former at a specified density, followed by flushing the water upward through the specimen until water was observed at the top of the specimen. The triaxial cell was then assembled and then back-pressure saturation increments were applied followed by consolidation. These specimens showed a tendency to collapse during the flushing and back-pressure saturation phases for the reasons noted above. The density of the specimen following flushing was known as the dimensions were recorded after this phase. It was however, impossible to determine the amount of densification occurring during back-pressure saturation.

In order to measure the densification that occurred during back-pressure saturation, the triaxial cell was calibrated and the cell fluid inflow/outflow during the saturation stage was monitored. Based on the change in cell fluid volume, the corresponding change in specimen volume could then be calculated. This method was found to yield reasonable results but due to the large change in volume of the cell fluid from cell pressure changes, compared with the volume change of sample, it was felt that the accuracy of this procedure was not adequate. This procedure was, however, continued on all tests conducted after number CAU17.

The specimens used for test numbers CAU24-CAU26 were, following test completion, frozen while still enclosed within the membrane in the triaxial cell. This procedure allowed the specimen to be accurately measured. As well, the frozen specimens were weighed in air and weighed in chilled alcohol to enable their volume to be measured. The volumes calculated using this method were corrected for the volumetric expansion of water due to the phase change to ice. Since the tests were conducted in an undrained mode, the pre-shear void ratio can be inferred to be the same as that obtained at the completion of the shearing of the specimen. It is believed that this procedure yields the most reliable indication of the pre-shear void ratio, but is a very time consuming and difficult procedure to perform.

After completion of all of the above mentioned procedures for void ratio determination, it was concluded that the most appropriate method of void ratio or density calculation was to simply back calculate the void ratio using the dry weight of the sand material and the final moisture content as determined at the completion of the shearing portion of the test. Calculation of void ratios using this approach involves making the assumption that the specimen is fully saturated prior to testing. This is a reasonable assumption as it was found from 'B' testing during the saturation phase that B values of greater than 0.95 were always obtained. Based on these findings, the values of void ratio or density used during the analysis of the results presented in this report were determined using the moisture content calculation procedure.

B17.3 TESTING PROGRAM FOR SEAMS

A cyclic and static direct and simple shear test program was conducted on the seams found within the claystone bedrock existing in the dam foundation.

The testing program comprised 7 static/cyclic direct shear tests and 1 static simple shear test. Most of the tests consisted of shearing the samples at a controlled strain rate until they had reached their residual shear strength, at which point various cyclic stresses were applied followed by further determination of the post cyclic residual shear strength. Deviations from this general procedure were adopted in selected tests. The test types, procedures followed and the principal variables are summarized in Table B17-3.

TABLE B17-3
TEST PROGRAM - SEAMS

TEST NUMBER	TEST TYPE	NORMAL STRESS (kPa)	PROCEDURE FOLLOWED
DS-1	DIRECT	1000	- shear to failure at 0.0048 mm/min, 3 residual determinations at 0.0048 mm/min, shear at 0.406 mm/min.
DS-2	DIRECT	1000	- shear to failure at 0.0048 mm/min, 3 residual determinations at 0.0048 mm/min, 10 cycles of shear stress between 95 and 150 kPa, residual determination at 0.0048 mm/min.
DS-3	DIRECT	1000	- shear to failure at 0.0048 mm/min, 1 residual determinations at 0.0048 mm/min, 10 cycles of shear stress between 135 and 250 kPa, 2 residual determination at 0.0048 mm/min.
DS-4	DIRECT	1000	- shear to failure at 0.0048 mm/min, 1 residual determinations at 0.0048 mm/min, 10 cycles of shear stress between 95 and 210 kPa, 2 residual determination at 0.0048 mm/min.
DSS-5	SAMPLE	1000	- tested in direct simple shear machine, attempted to shear specimen but unsuccessful when sample slid off of the base pedestal, sample was then attached to the base using plaster of paris and then sheared again, specimen removed from the simple shear machine and transferred to the direct shear machine were the peak shear strength and residual strength were determined by shearing at 0.0048 mm/min, sample had then deteriorated and cyclic testing was not possible.
DS-6	DIRECT	1000	- test conducted on artificially precut shear plane, sample sheared to failure at 0.0048 mm/min, 3 determination of residual at 0.0048 mm/min, apply 10 cycles of shear stress between 225 and 405 kPa, increase cyclic stress level by 23 kPa and apply 10 cycles, continue increasing cyclic stress level and apply 10 cycles until sample failed at cyclic stress levels of 200 to 630 kPa (10 increases in stress level), 2 residual determinations at 0.0048 mm/min.

TABLE B17-3 (Cont'd)

TEST PROGRAM - SEAMS

TEST NUMBER	TEST TYPE	NORMAL STRESS (kPa)	PROCEDURE FOLLOWED
DS-7	DIRECT	1000	- test conducted on artificially precut shear plane, sample sheared to failure at 0.0048 mm/min, 6 residual determinations at 0.0048 mm/min, 8 quick shears by hand cranking, 100 cycles of shear stress between 225 and 450 kPa, apply shear stress cycles of 225 to 495 kPa, which caused failure after 13 cycles, 2 residual determinations at 0.0048 mm/min.
DS-8	DIRECT	1000	- test ongoing at this time.

B17.3.1 Test Proceduresa) Sample Preparation

The test specimens were prepared by trimming them from the 193 mm diameter core samples obtained from the walls of the shafts excavated at the dam site. The samples were trimmed such that the seam would be subjected to shearing when set up in the direct shear machine. The specimens were trimmed while maintaining a known orientation such that the shearing was conducted in a direction perpendicular with the dams axis. The one simple shear test conducted was performed on a thick clay seam of nearly 25mm thickness. Square samples were generally trimmed from the core and were then cemented into the direct shear ring using Plaster of Paris. The final three tests (DS6, 7 and 8) were conducted on specimens in which a shear plane was developed by artificially precutting the claystone. Samples were

prepared in this manner because the quality of the large core samples was deteriorating and the natural clay seams were not uniform enough to conduct direct shear tests on them.

b) Testing Procedures - Static/Cyclic Direct Shear Tests

Normal stress of 1000 kPa were applied to the specimens using a dead weight and hanger system common to direct shear testing machines. The normal stress was maintained and the vertical deformation of the specimen was monitored until primary consolidation had ceased. The specimen was then sheared at a constant strain rate until a residual shear strength had been reached. In most cases the direction of shearing was reversed several times until the residual strength was observed to be constant in both direction. During this shearing, shear stress, lateral displacement and vertical displacements were monitored.

The specimens, while still in the shear box, were then removed from the constant strain rate application machine and transferred to a machine capable of applying cyclic shear stresses. The means of application of the cyclic shear stress was a Bellofram air cylinder connected through two parallel pressure regulating valves to a compressed nitrogen supply. An electronically controlled solenoid valve switched between the two pressure valves in order to provide an alternating high and low pressure to the Bellofram. In general the specimen was subjected to 10 cycles shear stress at predetermined stress levels. Following the cyclic loading, the specimen was then removed from the cyclic apparatus and returned to the constant strain rate machine where a further determination of the

residual shear strength was made. The procedures in specific tests varied somewhat from the above and the actual procedure followed in each test is highlighted in discussion of the test results.

c) Testing Procedures - Static/Cyclic Direct Sample Shear Test

One direct simple shear test was attempted on a specimen that displayed a clay seam of nearly 25mm thickness. The specimen was prepared in a similar manner to that for the direct shear specimens. The specimen was first subjected to the application of 1000 kPa normal stress, using a pneumatic load system, which was maintained until primary consolidation had ceased. Shearing of the sample then commenced in a constant strain rate mode, while the normal load was maintained. The first attempt to shear the sample was unsuccessful as the sample slid off the base pedestal. An additional constant strain rate shearing attempt was made after the specimen had been attached to the base pedestal using plaster of paris. During this test the sample failed at a location just slightly above the base pedestal. Due to the lack of success in testing this sample in the simple shear machine, it was transferred to the direct shear machine where the peak and residual shear strengths were determined. Unfortunately the sample had deteriorated to the point where cyclic stress applications could not be applied and as such the test was terminated.

B18.0 CYCLIC SHEAR STRENGTH TEST RESULTS

The detailed cyclic shear strength test results have been given in the UMA-Acres (1987). In the following section a brief summary has been given.

B18.1 TEST RESULTS FOR COMPACTED TILL

A summary of the results of the static tests is presented in Table B18-1. Detailed results, in tabular and graphical form, are contained in the UMA-Acres (1987). Graphical results comprise plots of deviator stress, pore pressure and stress ratio as a function of axial strain, and stress path in t - s space, $(\frac{\sigma_1 - \sigma_3}{2} \text{ vs } \frac{\sigma_1' + \sigma_3'}{2})$

The tables also give shear stress, τ_s and shear strain, ϵ_s . These are the octahedral invariants and are defined as follows for undrained triaxial compressions tests:

$$\tau_s = \frac{2}{3} (\sigma_1 - \sigma_3)$$

$$\epsilon_s = 2 \epsilon_1$$

The summary tables present both deviator stress at failure, defined as the condition of peak stress obliquity, and the peak deviator stress or that at 20% strain where a peak was not observed. Failure (peak obliquity) occurred at axial strains ranging from 7.5 to 11.8%, with an average of 9.5%.

TABLE B18-1
SUMMARY OF TEST RESULTS
STATIC TESTS ON COMPACTED TILL

TEST NUMBER	MOISTURE CONTENT (%)	VERTICAL CONSOL STRESS (kPa)	LATERAL CONSOL STRESS (kPa)	DEVIATOR STRESS FAILURE (kPa)	DEVIATOR STRESS PEAK (1) (kPa)	STRAIN AT FAILURE	NORMALIZED STRENGTH *	ϕ' (Degrees)	Af
CAU-1	15	450	300	340	381	11.8	0.567	21.2	0.384
CAU-1A	14	450	300	385	459	7.5	0.642	23.0	0.418
CAU-3	14	895	600	554	569	8.9	0.462	18.4	0.793
CAU-3A	14	900	600	713	755	9.4	0.594	21.9	0.484
CAU-5	14	1493	1000	945	1010	11.4	0.473	18.7	0.807
CAU-5A	14	1500	1000	1189	1252	10.6	0.595	21.9	0.485
CU-7	14	500	500	601	672	8.2	0.601	22.0	0.343
CU-9	14	1000	1000	889	909	8.4	0.445	17.9	0.560

$$\frac{(\sigma_1 - \sigma_3)_f}{2\sigma'_c}$$

* Normalized strength =

(1) Peak or 20% strain

Effective angles of shearing resistance, computed for each test assuming $c' = 0$, range between 17.9 and 23.0 degrees. Effective angles of shearing resistance observed at higher consolidation stresses were generally lower, implying that there may in fact be a small effective cohesion. As noted above, it was suspected that consolidation procedure A gave rise to residual pore pressures, and this was apparent in the high initial pore pressures during the undrained shearing stages of these tests. This may be responsible for the high pore pressure parameter at failure, A_f , and the lower effective angle of shearing resistance, in test 3 and 5. The average effective angle of shearing resistance for tests 1, 3 and 5 was 19.4 degrees; that for tests 1A, 3A and 5A was 22.3 degrees. Values of A_f ranged from 0.34 to 0.81. The average effective angle of shearing resistance obtained for the isotropic test was 20.0 (two values only).

B18.1.2 Cyclic Triaxial Tests

The key results of the cyclic tests are summarized in Tables B18-2 and B18-3. Table B18-2 presents the results of the cyclic portion of each test, while Table B18-3 summarizes the post-cyclic, static stage in the same format as Table B18-1. Detailed results in this report include cyclic stress-strain and pore pressure-strain relationships during the cyclic phases, and static results in the same form as for the static test series.

Axial strain after 10 cycles range from zero to 0.37%. Pore pressure induced during cycling varied between zero and 25 kPa, with the exception of test 8A in which a value of 133 kPa was recorded. Pore pressures measured in this test are

considered anomalous. The largest cyclic peak deviator stress imposed, expressed as a percentage of the static failure stress level, was 74% in test 2. In spite of the relatively high mean cyclic stress, this produced the second lowest cyclic axial strain and pore pressure.

TABLE B18-2
SUMMARY OF TEST RESULTS
STATIC TESTS ON COMPACTED TILL

TEST NUMBER	MOISTURE CONTENT (%)	VERTICAL CONSOL STRESS (kPa)	LATERAL CONSOL STRESS (kPa)	DEVIATOR STRESS MEAN (kPa)	DEVIATOR STRESS AMPLITUDE (kPa)	STRAIN AT 10 CYCLES (%)	PORE PRESSURE 10 CYCLES (kPa)
CAU-2	15	450	300	165	120	0.22	9
CAU-4	15	900	600	300	90	0.60	25
CAU-6	12	1500	1000	500	150	0	0
CAU-8	14	500	500	165	105	0.37	21
CAU-8A	14	500	500	160	105	0.16	133
CAU-10	12	1000	1000	215	135	0.03	21

TABLE B18-3
POST-CYCLIC STATIC PHASE - COMPACTED TILL

Test Number	Moisture Content (%)	Vertical Consol Stress (kPa)	Lateral Consol Stress (kPa)	Deviator Stress Failure (kPa)	Deviator Stress Static(1) (kPa)	Strain at Failure (%)	Normalized Strength *	ϕ' (Degrees)	Af
CAU-2	15	450	300	400	385	11.8	0.667	23.6	0.13
CAU-4	15	900	600	845	713	7.1	0.704	24.4	0.38
CAU-6	12	1490	1000	1096	1189	10.7	0.548	20.7	0.52
CAU-8	14	500	500	526	601	6.1	0.526	20.2	0.27
CAU-8A	14	500	500	525	601	10.3	0.525	20.1	0.28
CAU-10	12	1000	1000	909	889	8.4	0.455	18.2	0.46

* Normalized strength =
$$\frac{(\sigma_1 - \sigma_3)_f}{2 \frac{\sigma_3}{c}}$$

(1) Peak or 20% strain

Post static shearing produced failure strains ranging from 6.1 to 11.8%. Measured effective angles of shearing resistance, assuming $c' = 0$, ranged between 18.2 and 24.4 degrees. The average value for the anisotropic tests were 22.9 degrees and that for the isotropic tests was 19.5 degrees. Values of Af varied between 0.13 and 0.52,

On the basis of a comparison between the static tests and the post-cyclic static tests, it would appear that no significant strength degradation can be attributed to the imposition of 10 cycles of deviator stress, at peak stresses below 74% of static failure stress levels.

The stress path plots for isotropically and anisotropically consolidated undrained cyclic and static triaxial tests are shown on Plates B-237 to B-239.

B18.2 TEST RESULTS FOR SURFICIAL SAND ALLUVIUM

B18.2.1 Static Triaxial Tests

A summary of the results of the static triaxial tests is presented in Table B18-4. Detailed results, in tabular and graphical form, are contained in the UMA-Acres (1987). Graphical results comprise plots of deviator stress, pore pressure and stress ratio as a function of axial strain, and stress path in t-s space, $\frac{(\sigma_1 - \sigma_3)}{2}$ vs $\frac{(\sigma_1' + \sigma_3')}{2}$

The tables also give shear stress, τ_s and shear strain, ϵ_s . These are the octahedral invariants and are defined as follows for undrained triaxial compression tests:

$$\tau_s = \frac{2}{3} (\sigma_1 - \sigma_3)$$

$$\epsilon_s = 2 \epsilon_1$$

The summary tables present both deviator stress at failure, defined as the condition of peak obliquity, and the peak deviator stress or that at 20% strain where a peak was not observed. Failure (peak obliquity) occurred at axial strains ranging from, 0.6% to 4.1% with an average of 2.0%.

Effective angles of shearing resistance computed for each test assuming $c' = 0$, ranged between 22.6 and 35.9 degrees. The rather large range in effective angles of shearing resistance determined is not unexpected as the densities at which the tests were conducted also varied substantially.

B18.2.2 Cyclic Triaxial Tests

The results of the cyclic tests are summarized in Table B18-5. Detailed results of the cyclic tests are presented in the UMA-Acres (1987). Plots given in this report include cyclic stress-strain and pore pressure-strain relationships during the cyclic phases, and accumulated strain versus number of cycles. As mentioned earlier, failure of these specimens was assumed to have occurred when the cyclic strains were observed to be accelerating.

TABLE B18-4
SUMMARY OF TEST RESULTS
STATIC TESTS ON RECONSTITUTED SAND ALLUVIUM

Test Number	Moisture Content (%)	Pre-Shear Void Ratio	Vertical Consol Stress (kPa)	Lateral Consol Stress (kPa)	Deviator Stress Failure (kPa)	Deviator Stress Peak (1) (kPa)	Strain at Failure (%)	Normalized Strength *	ϕ' (Degrees)	Af
CAU-11	18	0.477	900	600	754.5	785.0	4.1	0.653	35.9	0.681
CAU-14	20	0.526	900	600	347.4	397.4	1.5	0.331	23.4	3.109
CAU-14A	20	0.525	900	600	381.4	426.7	1.2	0.356	23.3	2.123
CAU-17	21	0.541	900	600	304.1	408.1	1.4	0.340	23.4	2.789
CAU-19	25	0.655	900	600	94.1	116.0	1.8	0.290	24.0	2.368
CAU-22	18	0.483	900	600	654.4	692.2	3.5	0.576	35.7	0.867
CU-25	24	0.630	300	200	109.7	132.5	0.6	0.332	22.6	2.543

$$\frac{(\sigma'_1 - \sigma'_3)f}{2\sigma'_3}$$

* Normalized strength =

(1) Peak or 20% strain

TABLE B18-5
SUMMARY OF TEST RESULTS
CYCLIC TESTS ON SAND ALLUVIUM

Test Number	Moisture Content (%)	Pre-Shear Void Ratio	Vertical Consol Stress (kPa)	Lateral Consol Stress (kPa)	Deviator Stress Low (kPa)	Deviator Stress High (kPa)	Number of Cycles Failure	Normalized Shear Strength* (%)	Strain at Failure
CAU-12	17	0.460	900	600	425	785	110	0.654	2.0
CAU-13	19	0.495	900	600	375	720	375	0.600	5.0
CAU-15	20	0.534	900	600	290	507	507	0.423	1.5
CAU-16	20	0.523	900	600	305	480	425	0.400	2.2
CAU-18	20	0.537	900	600	300	505	152	0.421	0.7
CAU-20	23	0.613	300	200	100	200	16	0.500	7.0
CAU-21	23	0.612	300	200	100	170	57	0.425	5.7
CAU-23	17	0.448	900	600	540	900	567	0.750	5.0
CAU-26	23	0.598	300	200	100	180	180	0.450	5.5
CAU-27	21	0.553	300	200	100	255	1	0.638	11.2
CAU-28	21	0.546	300	200	100	200	1	0.500	5.0
CAU-29	21	0.554	300	200	125	185	9	0.463	3.9

$$\text{*Normalized Strength} = \frac{(\sigma_1' - \sigma_3') f}{2\sigma_3'}$$

B18.3 TEST RESULTS FOR SEAMS

B18.3.1 Static/Cyclic Direct Shear Tests

A summary of the results of the direct shear test is presented in Table B18-6. Detailed results of the static and cyclic portions of each test, are presented in tabular and graphical form in the UMA-Acres (1987). Graphical results comprise plots of shear stress and vertical displacement versus horizontal displacement for the pre-and post-cyclic portions of the tests. Results presented for the cyclic portion include plots of shear stress versus horizontal displacement and accumulated displacement versus number of cycles applied.

Summary Table B18-6 presents peak shear strength and residual shear strength both before and after cyclic loading as well as the displacements measured during the cyclic portions of the tests.

Two distinct levels of strength were noted during this testing. For the tests conducted in the natural clay seam materials the peak shear strength of the clay seams was found to average 365 kPa, while the residual strength was found to range between 210 and 270 kPa with an average of 243 kPa for an applied normal stress of 1000 kPa. Failure of the specimens occurred at horizontal displacements ranging from 1.8 mm to 3.6 mm with an average of 2.7 mm. The other tests which were conducted on specimens which had an artificially precut shear plan displayed peak shear strengths of 544 and 540 kPa and residual strengths prior to cyclic stress applications of 450 and 420 kPa for a normal load of 1000 kPa. The peak shear stresses were achieved after horizontal displacements of 0.6 mm.

Effective peak angles of shearing resistance, computed for the tests conducted on the natural clay seam samples assuming $c' = 0$, range between 19 and 21 degrees. Effective peak angles of shearing resistance for the artificially precut shear planes varied between 28 and 30 degrees. The residual angles of shearing resistance for the natural clay seams were found to range between 12 and 15 degrees while those for the precut shear plans ranged from 23 to 24 degrees.

Plate B-240 shows the normalized cyclic residual shear stress versus the horizontal displacement after application of ten cycles of the residual shear stress. In this test the sample was sheared to residual stress statically. Then ten cycles of the different residual shear stress were applied on the same sample and the horizontal displacements were measured. As shown on Plate B-230, the cyclic residual shear stress corresponding to a large horizontal displacement is, due to the turbulent shear zone effect (Skempton (1985)), approximately 30 percent higher than the static residual shear stress.

B18.3.2 Static/Cyclic Direct Simple Shear Test

As mentioned before the one direct simple shear test attempted was mostly unsuccessful and as such the only information available from the test are the static shear strength and displacement characteristics of this test. The specimen displayed a shear strength of 813 kPa, corresponding to a peak angle of shearing resistance of 39 degrees, for an applied normal stress of 1000 kPa and the peak was observed to occur after a shear displacement of 2.3 mm. A residual shear strength of 435 kPa, which corresponds to a residual angle of shearing resistance of 24 degrees, was measured on this specimen.

TABLE B18-6
SUMMARY OF TEST RESULTS
STATIC/CYCLIC TESTS ON CLAY SEAMS

Test Number	Normal Stress (kPa)	Peak Shear Stress (kPa)	Displacement at Peak Strength (mm)	Residual Shear Strength (kPa)	Cyclic Shear Stress Low-High (kPa)	Number of Cycles	Cyclic Displacement (mm)	Post Cyclic Residual Shear Strength (kPa)
DS-1	1000	378.6	1.8	270	NA	NA	NA	240
DS-2	1000	343.0	3.6	220	95-150	10	4.0	
DS-3	1000	372.2	3.4	270	135-250	10	0.2	275
DS-4	1000	no peak	1.8	210	95-210	10	0.1	210
DS-5	1000	813.2	2.3	435				
DS-6	1000	543.5	0.6	450	225-405	10	0.1	
					225-428	10	0.1	
					220-450	10	0.1	
					260-470	10	0.1	
					225-493	10	0.1	
					290-526	10	0.2	
					242-548	10	0.2	
					311-563	10	0.2	
					225-585	10	0.2	
					220-608	10	0.3	
					200-630	1	fail	450
DS-7	1000	526.9	0.5	420	225-450	100	0.1	
					225-495	13	fail	420
DS-8	1000	517.6	0.3	260	13-260	495	0.1	265
					140-235	480	0.1	250
					140-280	500	0.1	250
					130-295	2	fail	245

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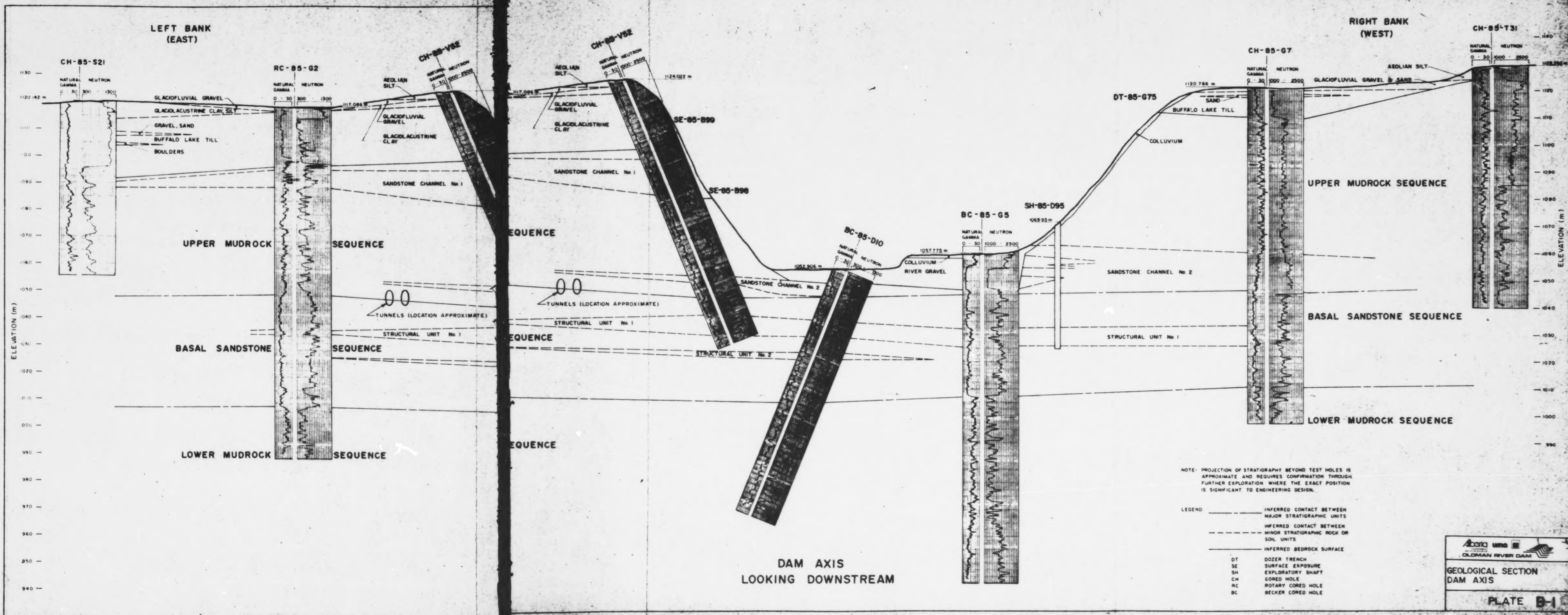
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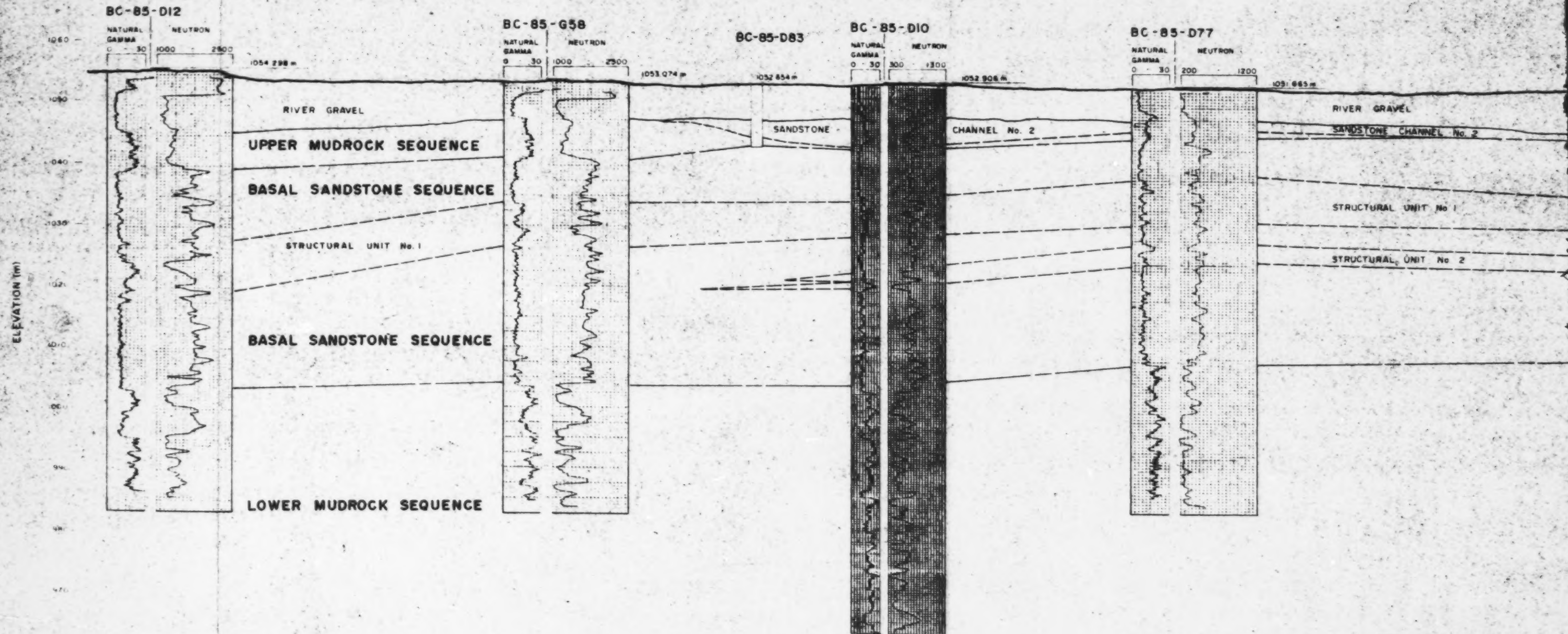
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UPSTREAM
(NORTH)



RIVER VALLEY
LOOKING EAST

BC-85-D77

NATURAL GAMMA
0 30 200 1200

NEUTRON

1051.665 m

BC-85-D8

NATURAL GAMMA
0 30 1000 2500

NEUTRON

1051.455 m

BC-85-S16

NATURAL GAMMA
0 30 1000 2500

NEUTRON

1052.555 m

No. 2

RIVER GRAVEL

SANDSTONE CHANNEL No. 2

STRUCTURAL UNIT No. 1

STRUCTURAL UNIT No. 2

SANDSTONE CHANNEL No. 2

UPPER MUDROCK SEQUENCE

BASAL SANDSTONE SEQUENCE

STRUCTURAL UNIT No. 1

STRUCTURAL UNIT No. 2

BASAL SANDSTONE SEQUENCE

RIVER GRAVEL

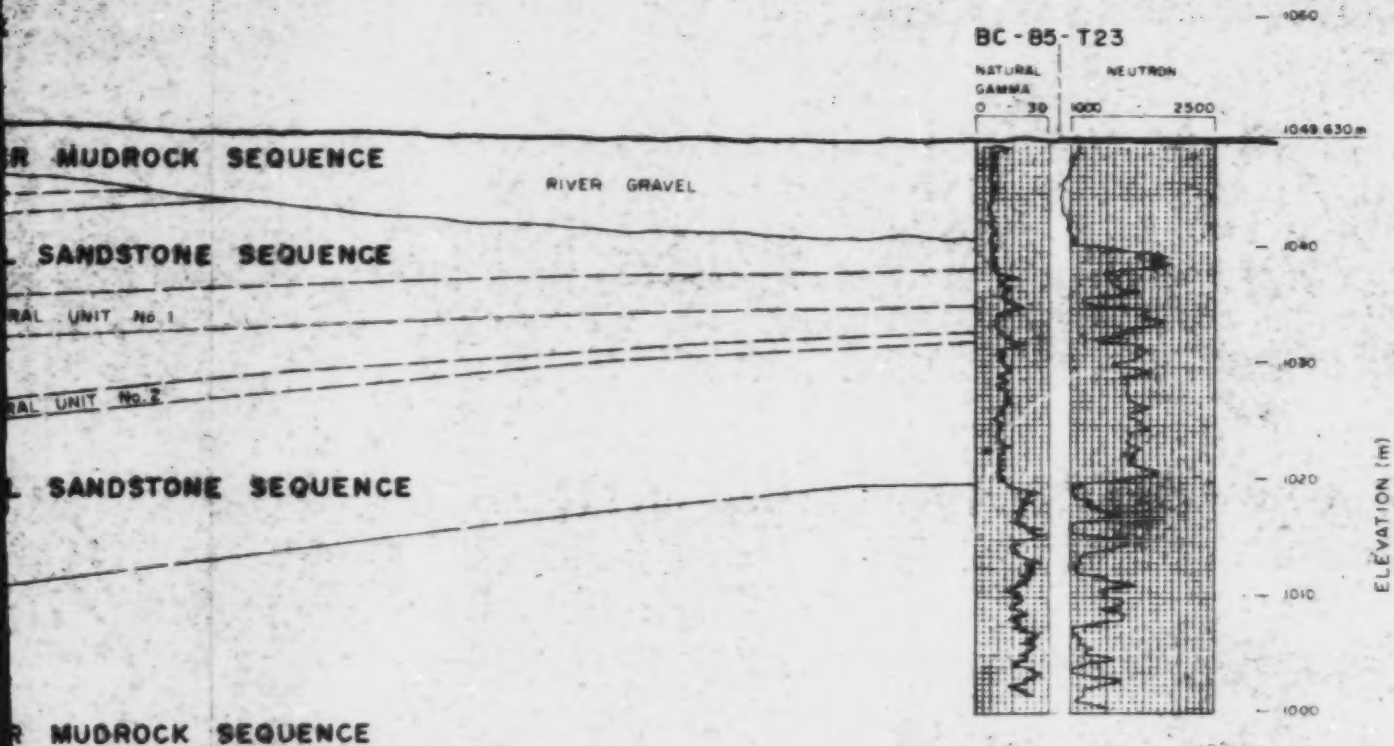
LOWER MUDROCK SEQUENCE

RIVER VALLEY
LOOKING EAST

NOTE: PROJECTION OF STRATIGRAPHY BEYOND
APPROXIMATE AND REQUIRES CONFIRMATION
FURTHER EXPLORATION WHERE THE
IS SIGNIFICANT TO ENGINEERING DESIGN

LEGEND: ——— INFERRED CORRELATION
MAJOR STRATIGRAPHIC UNITS
- - - - - INFERRED CORRELATION
MINOR STRATIGRAPHIC UNITS
SOIL UNITS
————— INFERRED BEYOND
DT DOZER TRENCH
SE SURFACE EXPOSURE
SH EXPLORATORY HOLE
CH CORED HOLE
RC ROTARY CORE
BC BECKER CORE

**DOWNSTREAM
(SOUTH)**



NOTE: PROJECTION OF STRATIGRAPHY BEYOND TEST HOLES IS APPROXIMATE AND REQUIRES CONFIRMATION THROUGH FURTHER EXPLORATION WHERE THE EXACT POSITION IS SIGNIFICANT TO ENGINEERING DESIGN.

LEGEND

----- INFERRED CONTACT BETWEEN MAJOR STRATIGRAPHIC UNITS

----- INFERRED CONTACT BETWEEN MINOR STRATIGRAPHIC ROCK OR SOIL UNITS

----- INFERRED BEDROCK SURFACE

DT DOZER TRENCH

SE SURFACE EXPOSURE

SH EXPLORATORY SHAFT

CH CORED HOLE

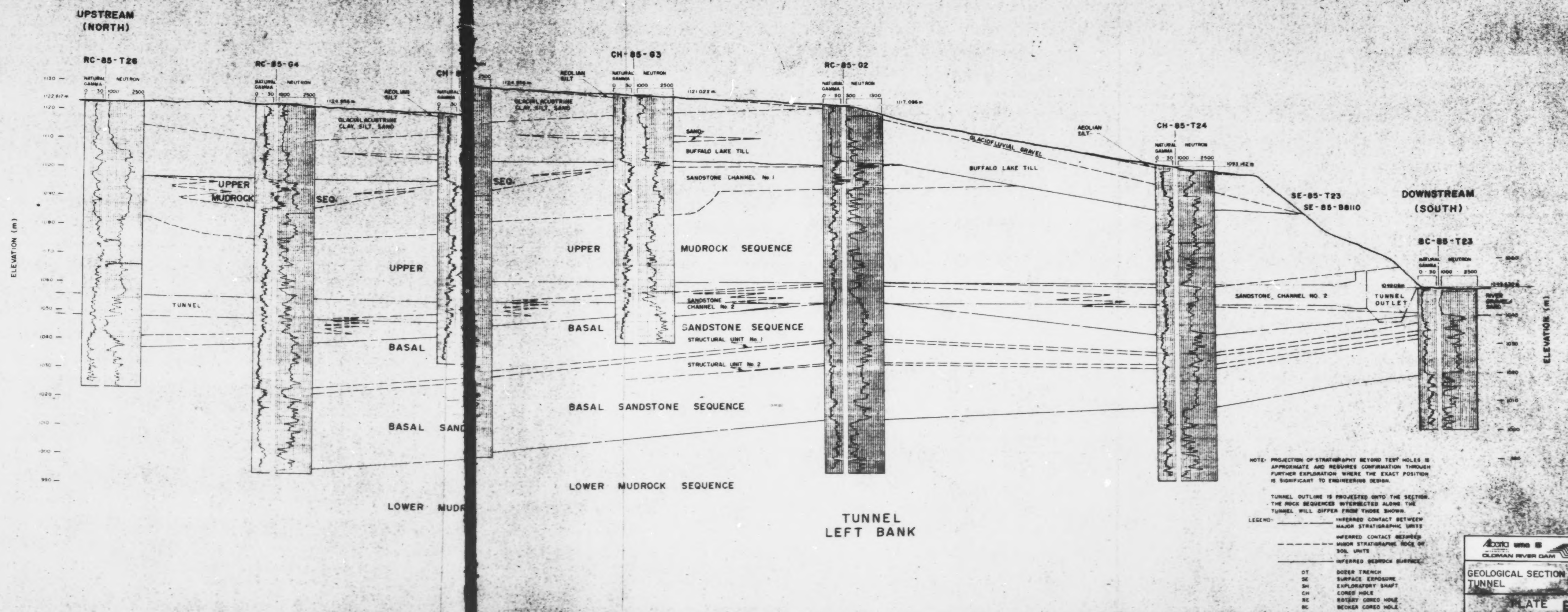
RC ROTARY CORED HOLE

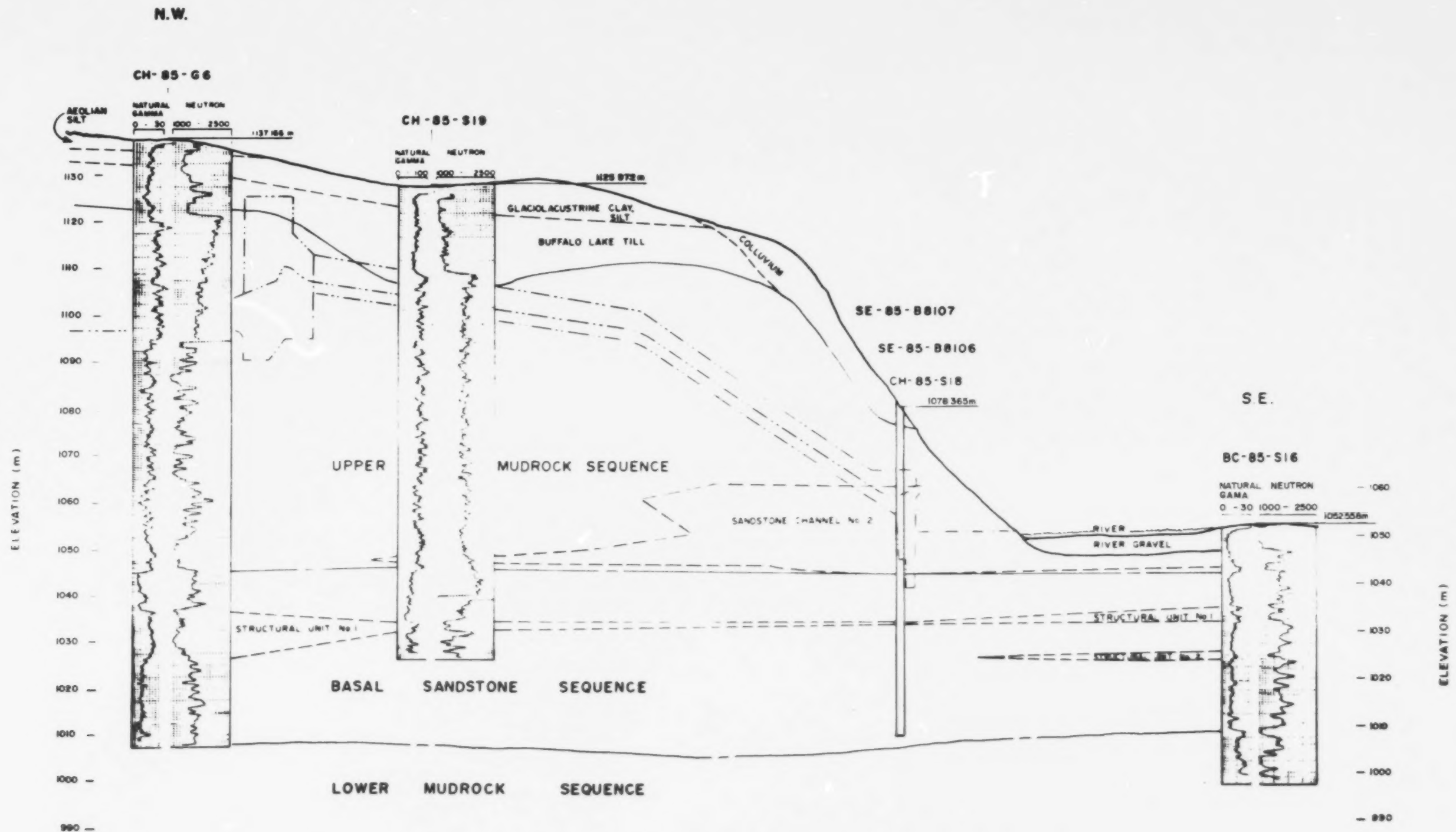
BC BECKER CORED HOLE

Alberta WIND ENERGY
OLDMAN RIVER DAM

GEOLOGICAL SECTION
RIVER VALLEY

PLATE B-2



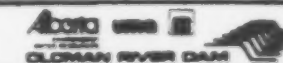


NOTE: PROJECTION OF STRATIGRAPHY BEYOND TEST HOLES IS APPROXIMATE AND REQUIRES CONFIRMATION THROUGH FURTHER EXPLORATION WHERE THE EXACT POSITION IS SIGNIFICANT TO ENGINEERING DESIGN.

SPILLWAY OUTLINE IS PROJECTED ONTO THE SECTION. THE ROCK SEQUENCES INTERSECTED ALONG THE SPILLWAY WILL DIFFER FROM THOSE SHOWN.

LEGEND

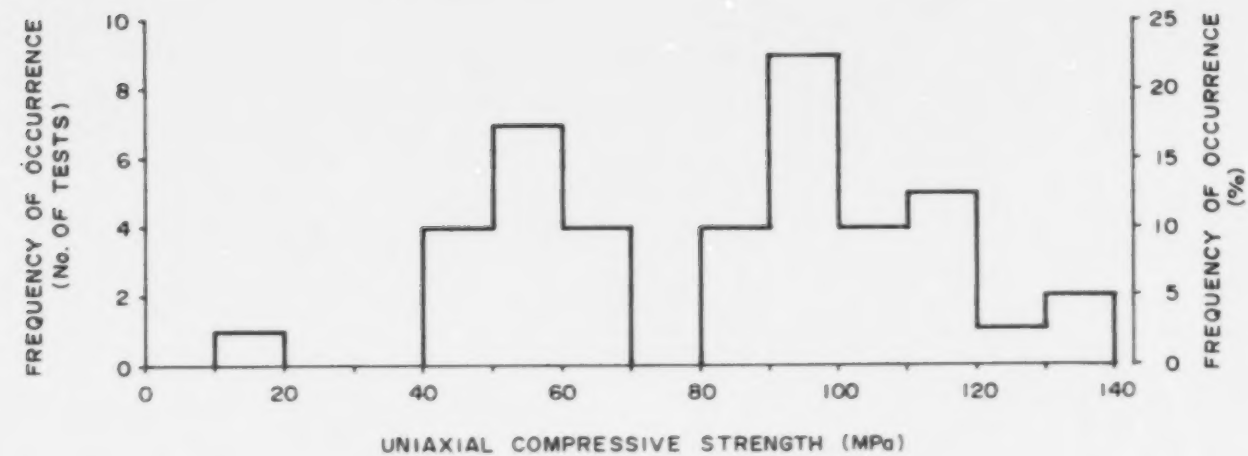
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- - -	INFERRED CONTACT BETWEEN MINOR STRATIGRAPHIC ROCK OR SOIL UNITS
---	INFERRED BEDROCK SURFACE
DT	DOZER TRENCH
SE	SURFACE EXPOSURE
SH	EXPLORATORY SHAFT
CH	CORED HOLE
RC	ROTARY CORED HOLE
BC	BECKER CORED HOLE



GEOLOGICAL SECTION
SPILLWAY

PLATE B-4

	RANGE (MPa)	AVERAGE (MPa)	No. OF TESTS
VB	12 - 116	79	15
AB	44 - 132	84	26

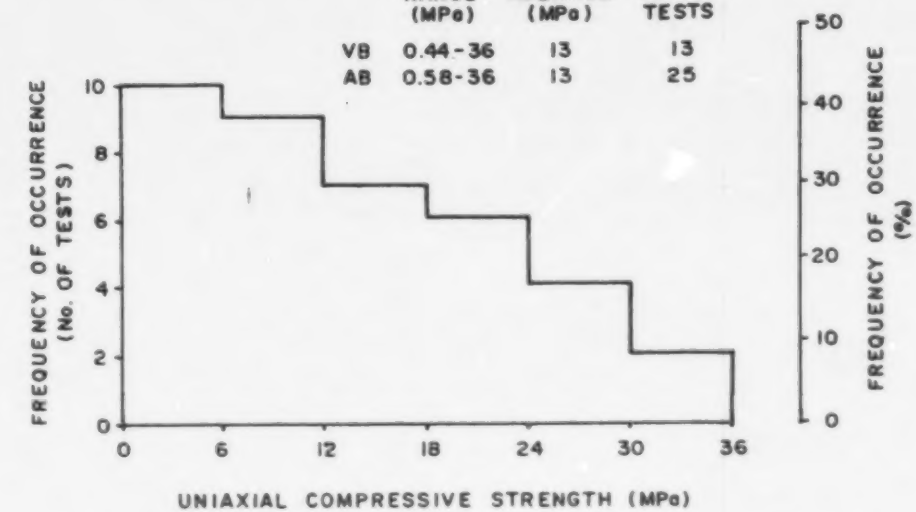


SANDSTONE

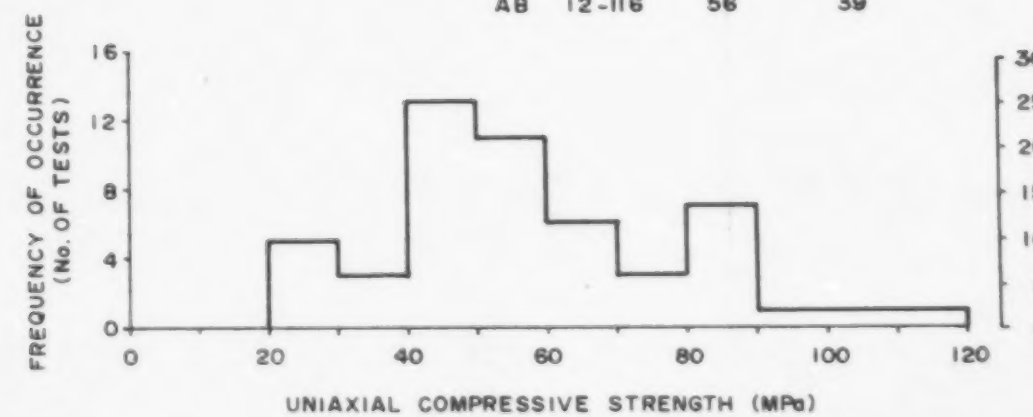
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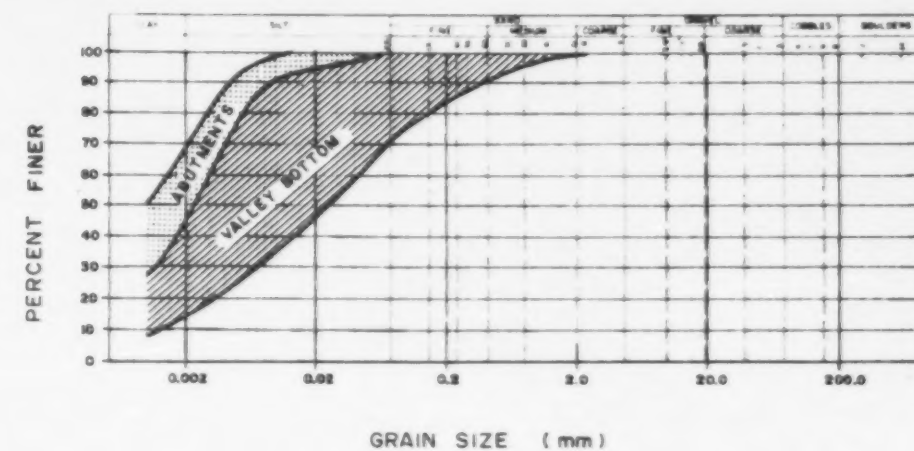
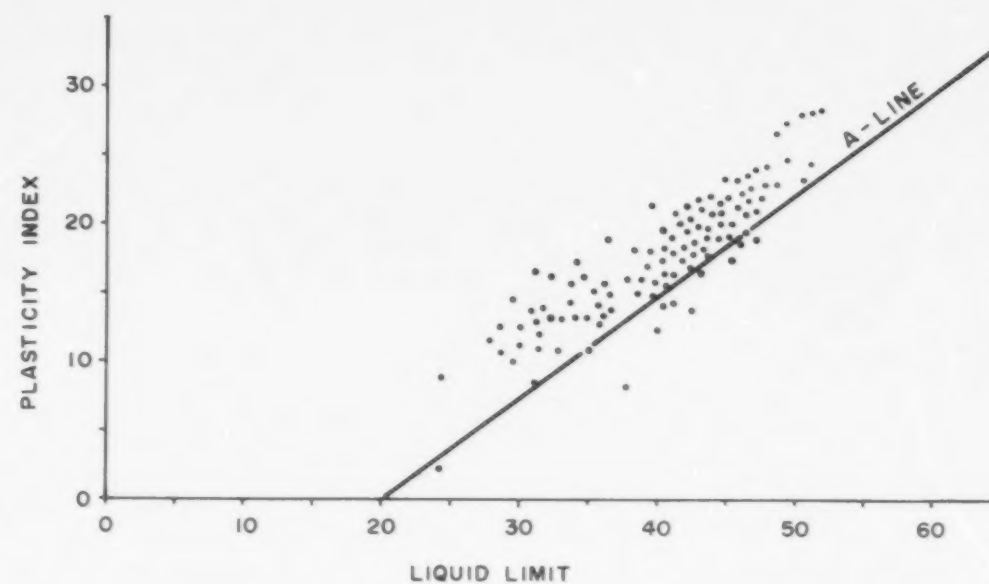
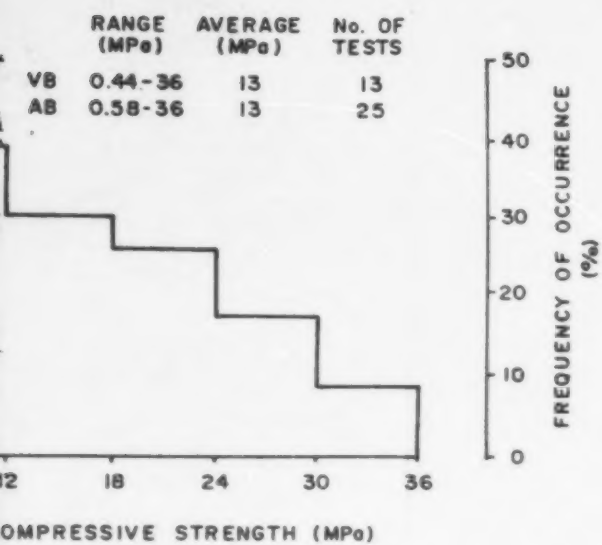
VB - VALLEY BOTTOM
AB - ABUTMENTS

	RANGE (MPa)	AVERAGE (MPa)	No. OF TESTS
VB	0.44 - 36	13	13
AB	0.58 - 36	13	25

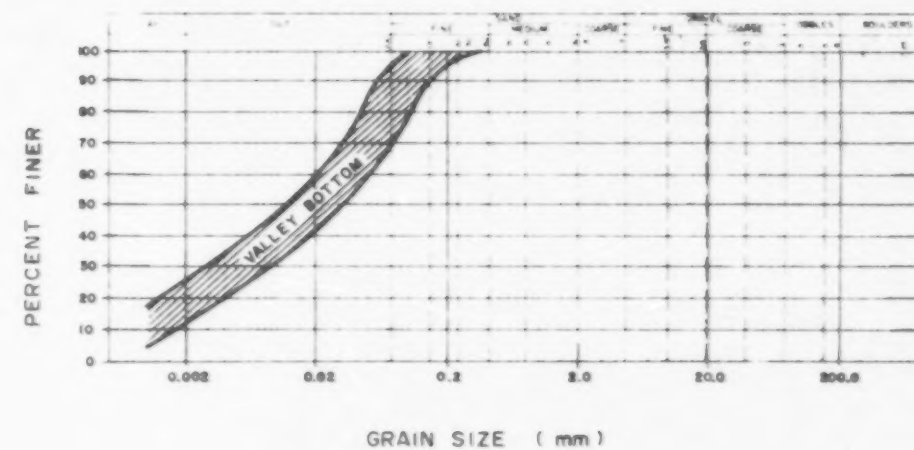
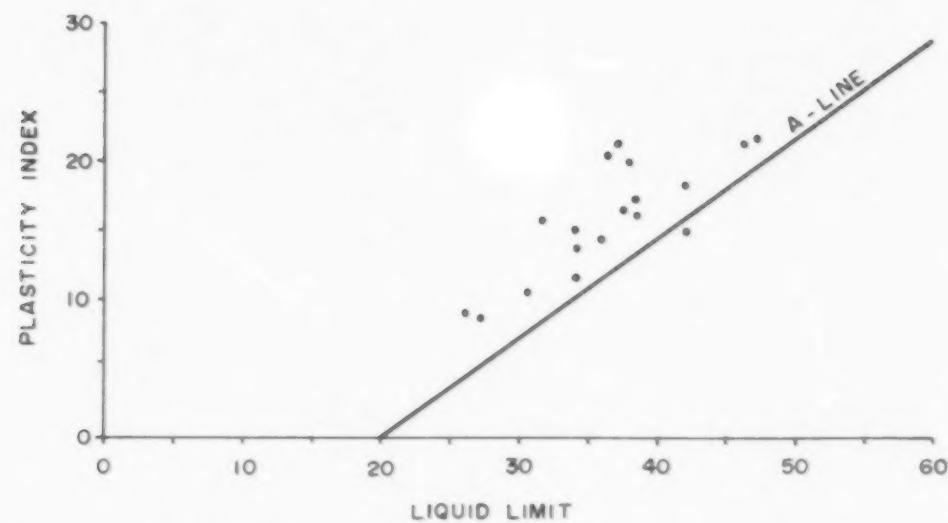
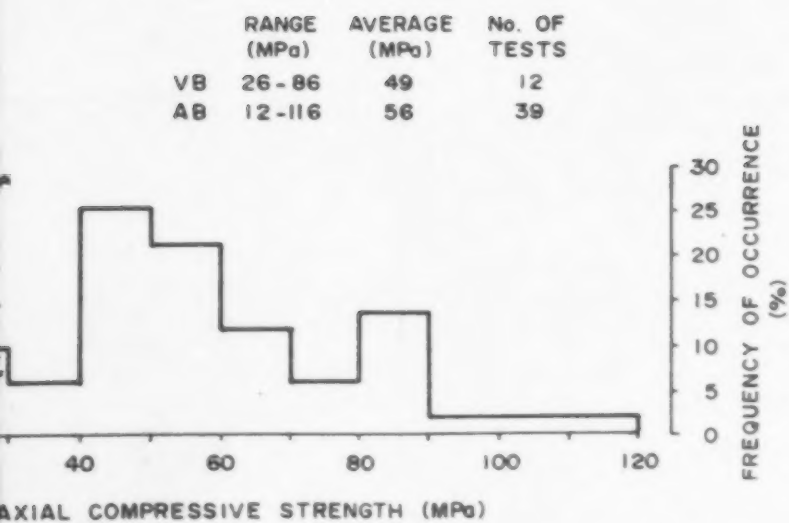


	RANGE (MPa)	AVERAGE (MPa)	No. OF TESTS
VB	26 - 86	49	12
AB	12 - 116	56	39

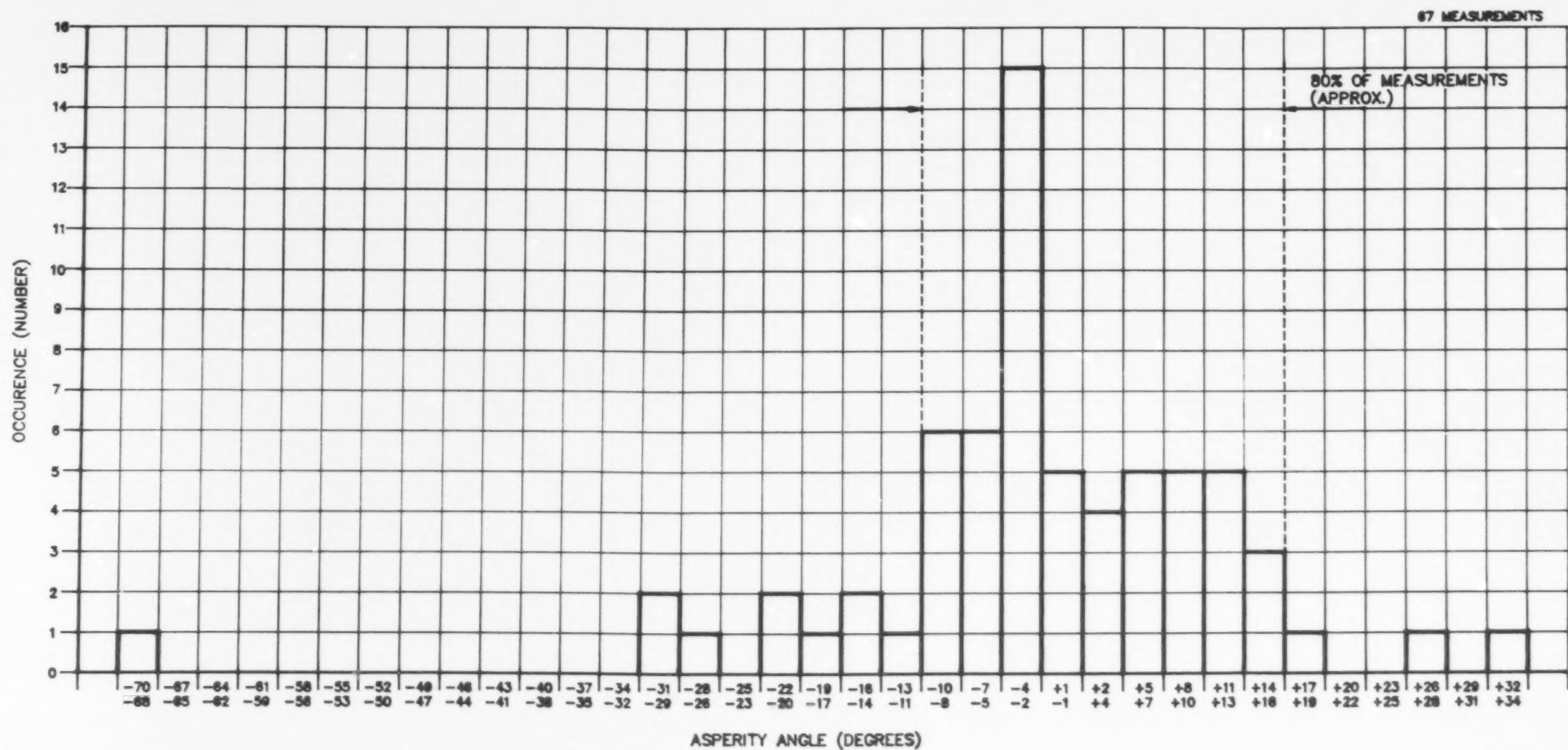




CLAYSTONE



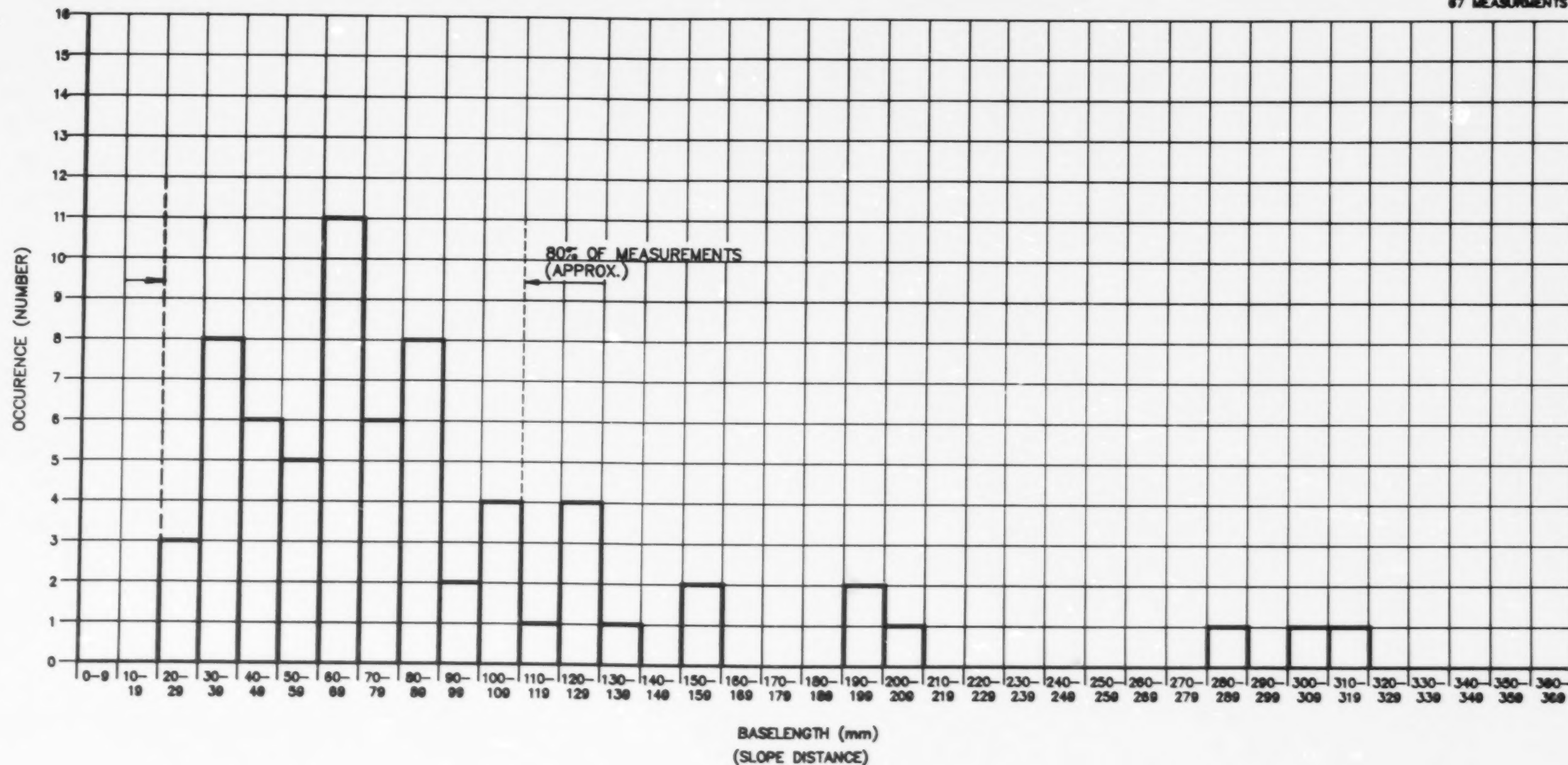
SILTSTONE



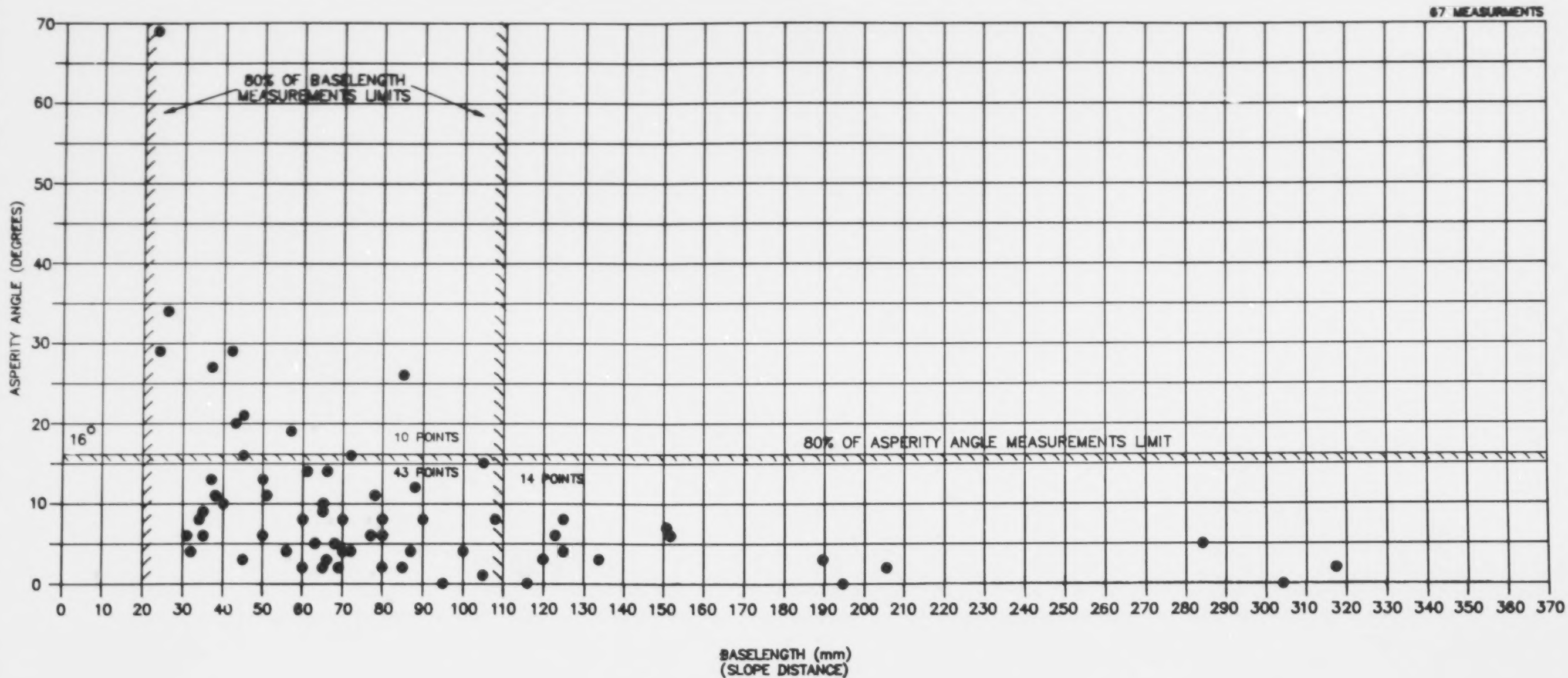
+ ANGLE = WESTERLY DIP
 - ANGLE = EASTERLY DIP

HISTOGRAM OF ASPERITY ANGLES ON UPPER WALL ROCK SURFACE SEAM 3L

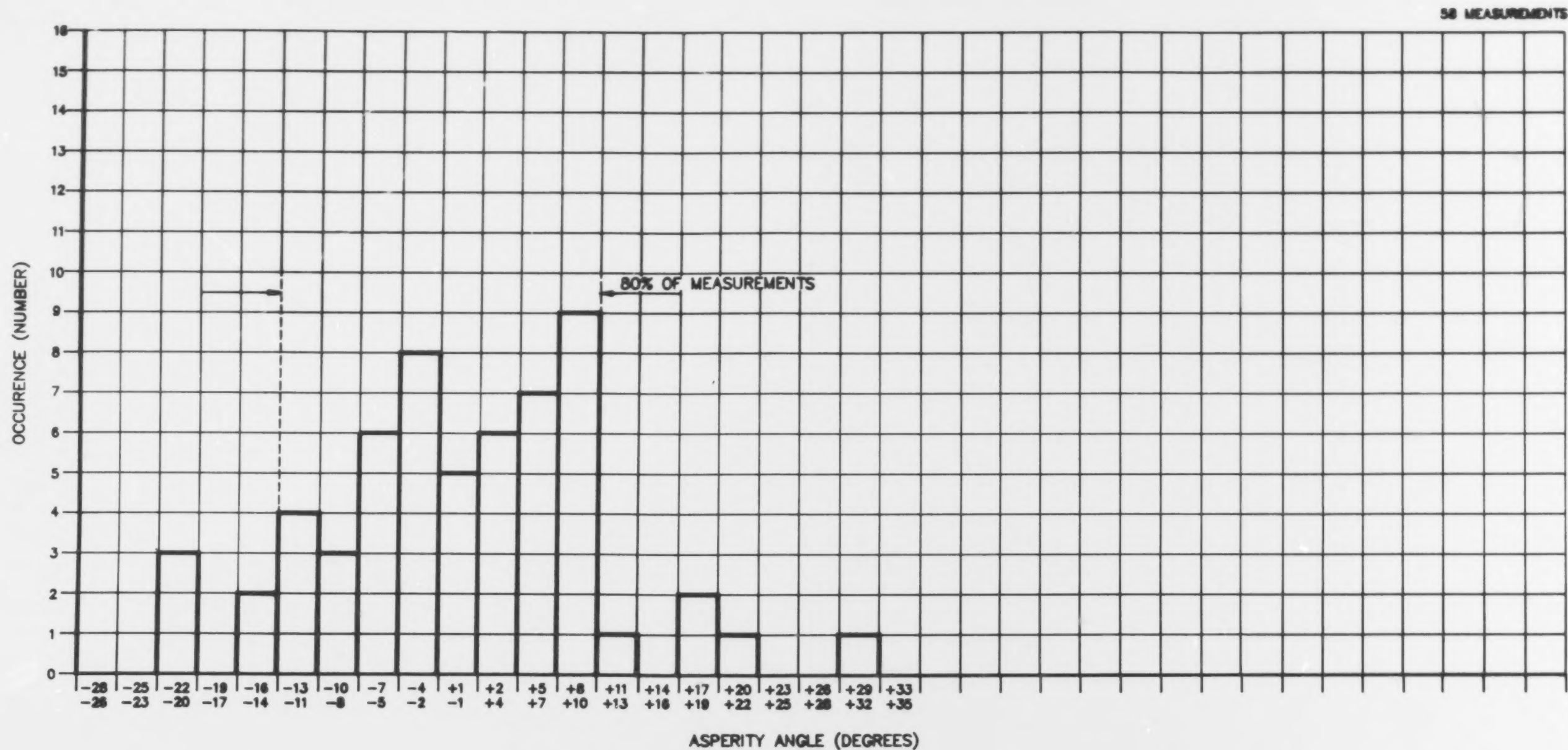
67 MEASUREMENTS



HISTOGRAM OF BASELENGTHS ON UPPER WALL ROCK SURFACE OF SEAM 3L

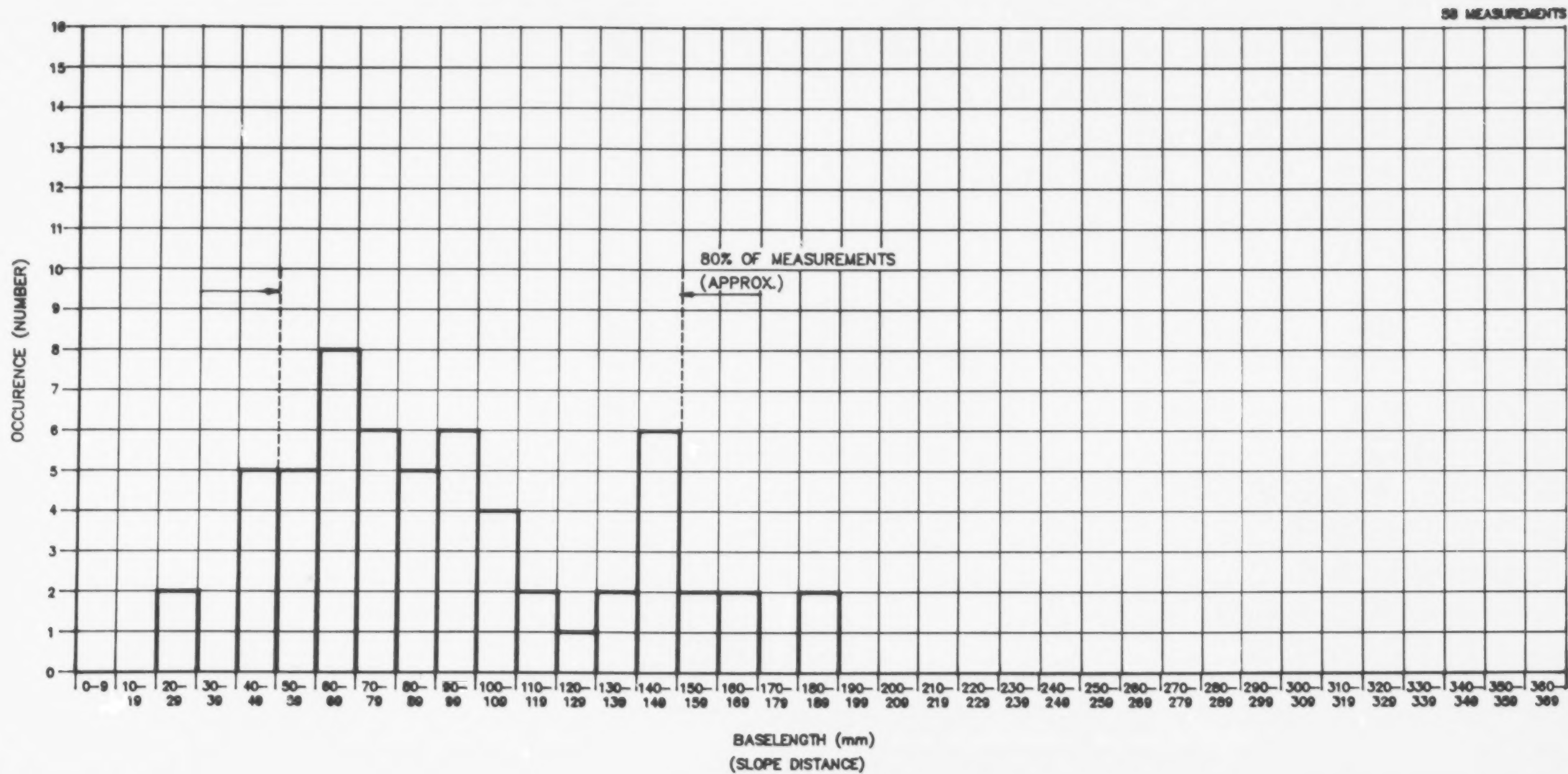


ASPERITY ANGLE VS. BASELENGTH FOR UPPER WALL ROCK SURFACE OF SEAM 3L

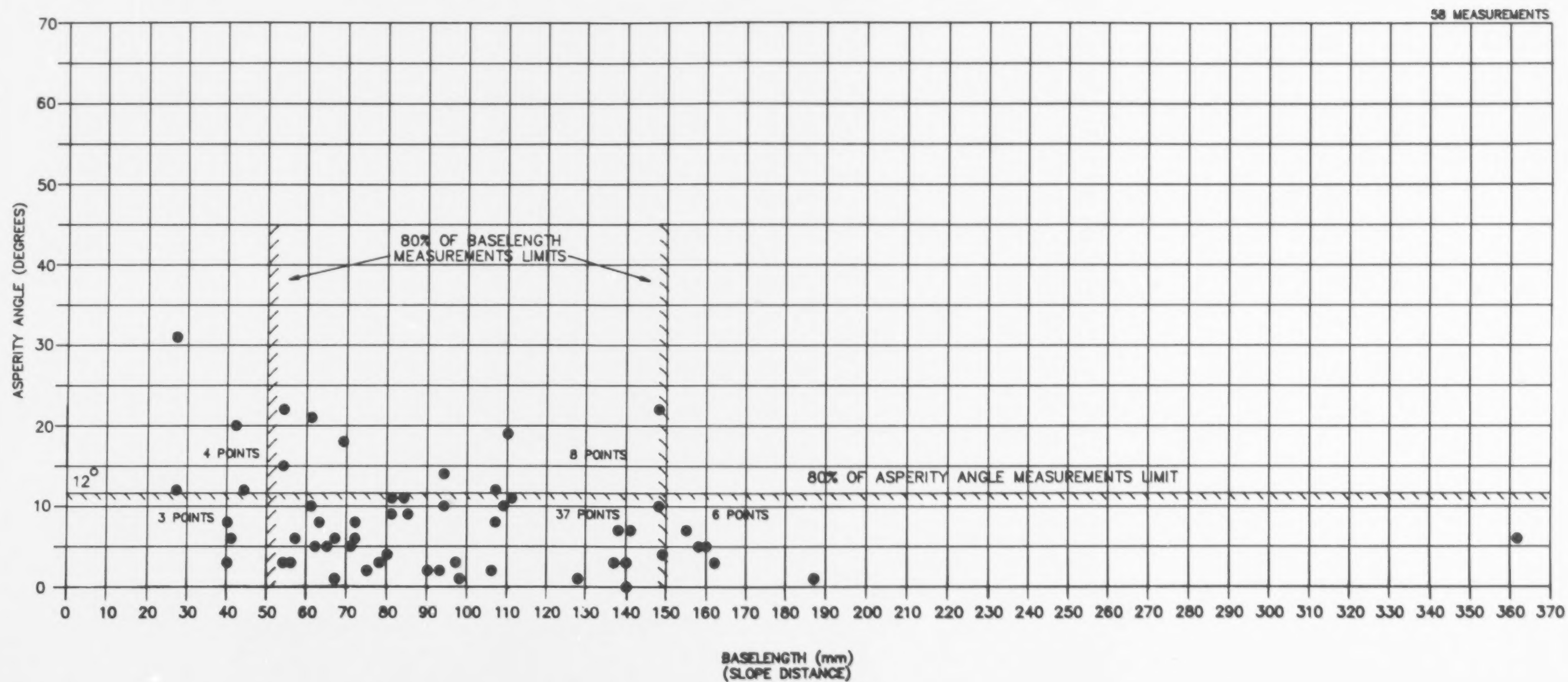


+ ANGLE = WESTERLY DIP
 - ANGLE = EASTERLY DIP

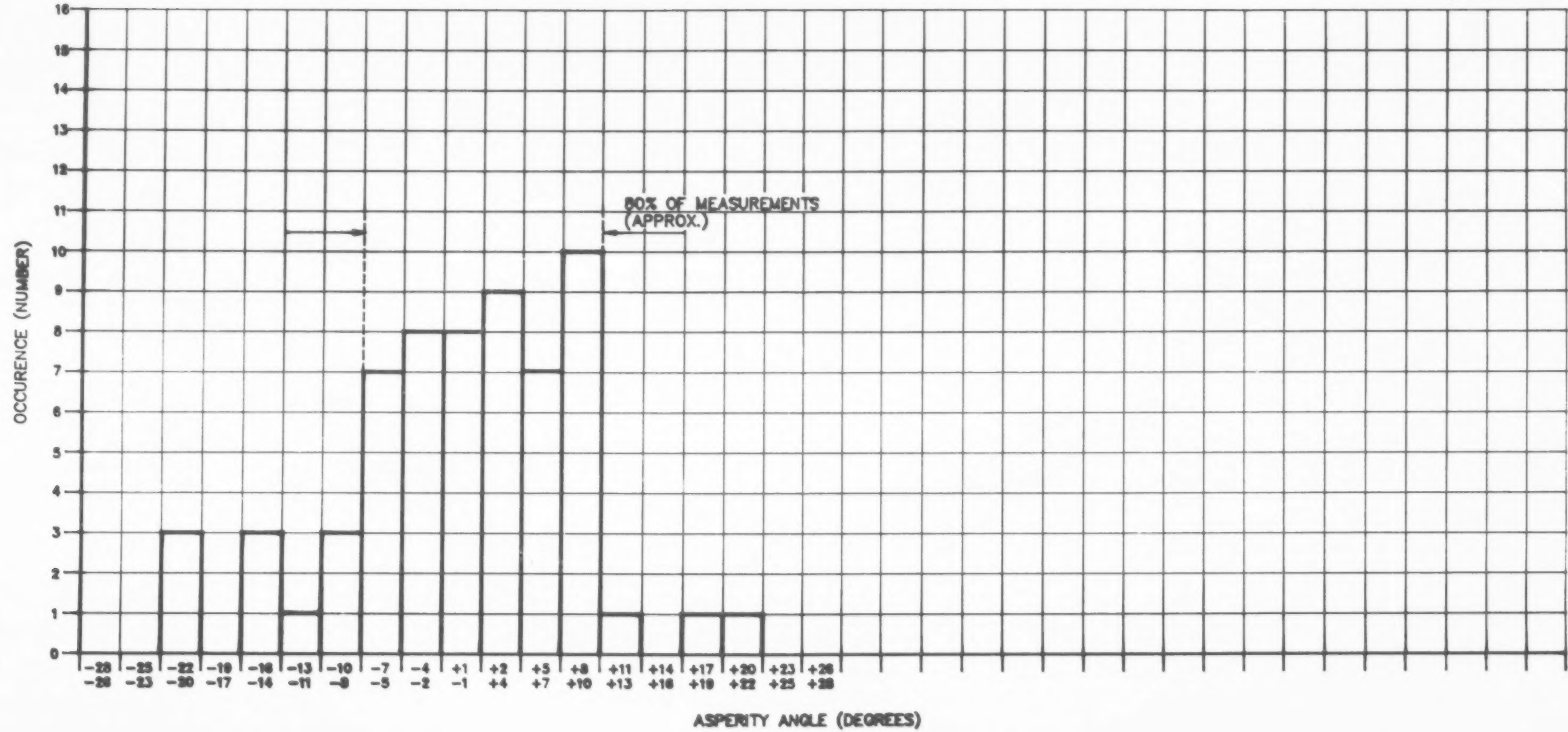
HISTOGRAM OF ASPERITY ANGLES ON LOWER WALL ROCK SURFACE OF SEAM 3L



HISTOGRAM OF BASELENGTHS ON LOWER WALL ROCK SURFACE OF SEAM 3L

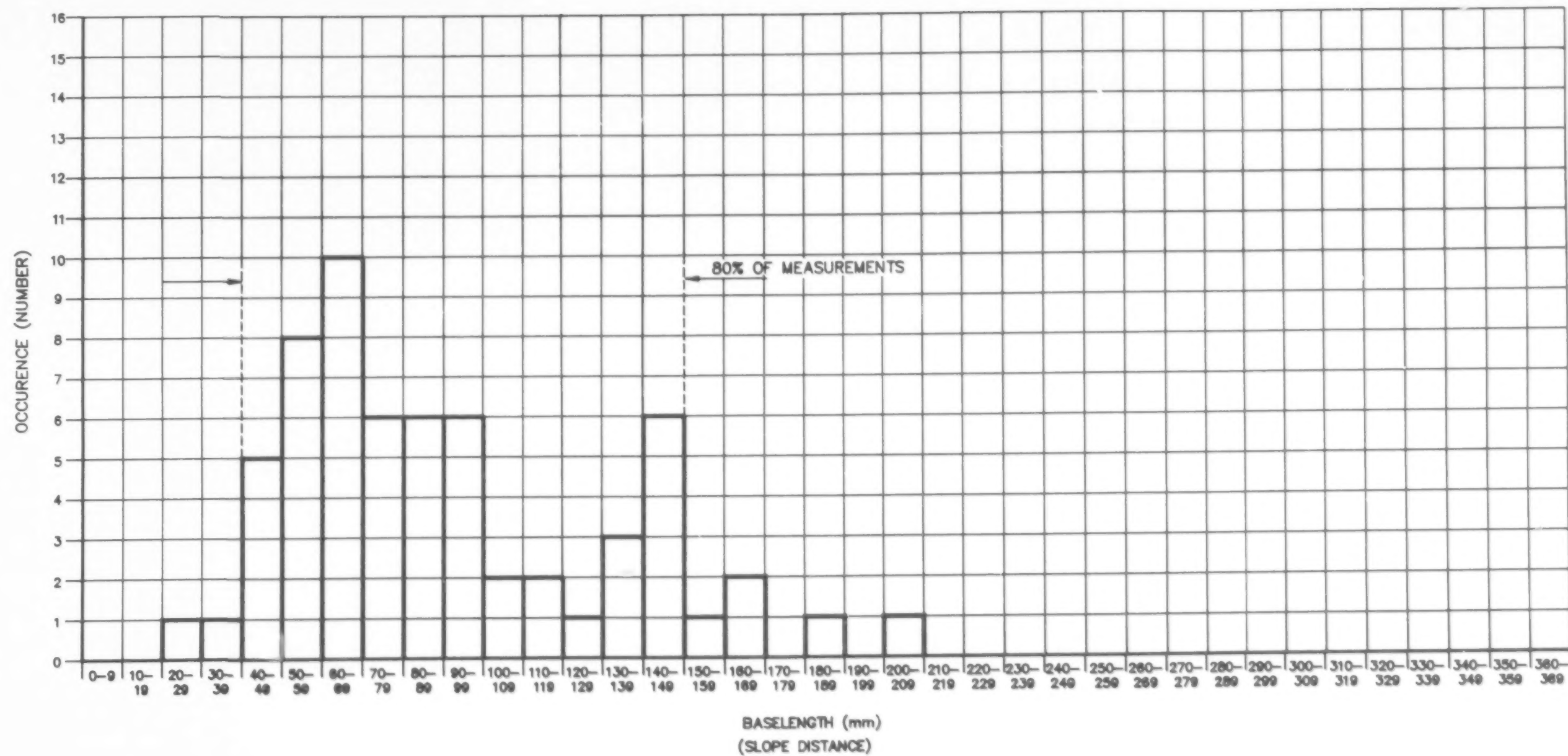


ASPERITY ANGLE VS. BASELENGTH FOR LOWER WALL ROCK SURFACE OF SEAM 3L

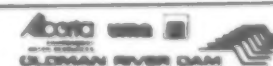


+ ANGLE = WESTERLY DIP
- ANGLE = EASTERLY DIP

HISTOGRAM OF ASPERITY ANGLES ON LOWER SURFACE OF UPPER ZONE SEAM 3L

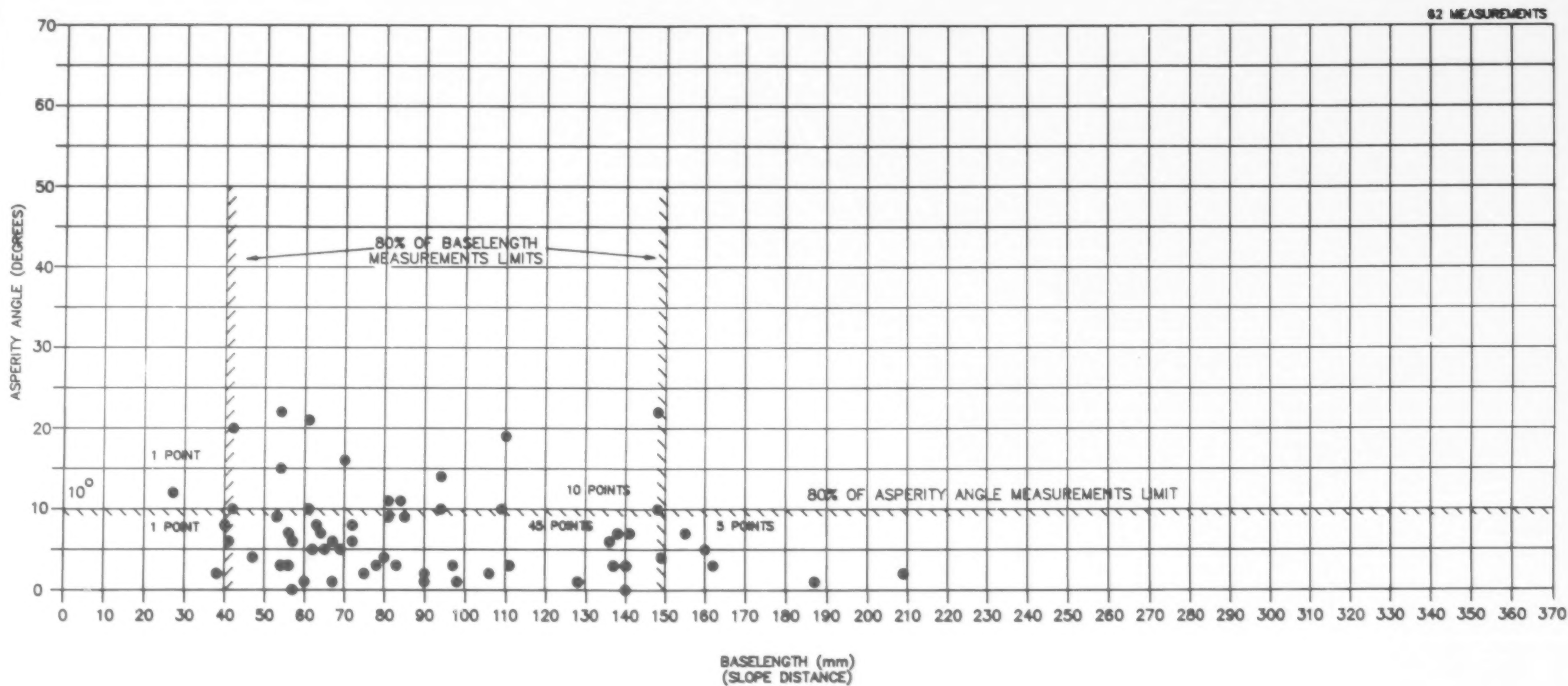


HISTOGRAM OF BASELENGTHS ON LOWER SURFACE OF UPPER ZONE SEAM 3L



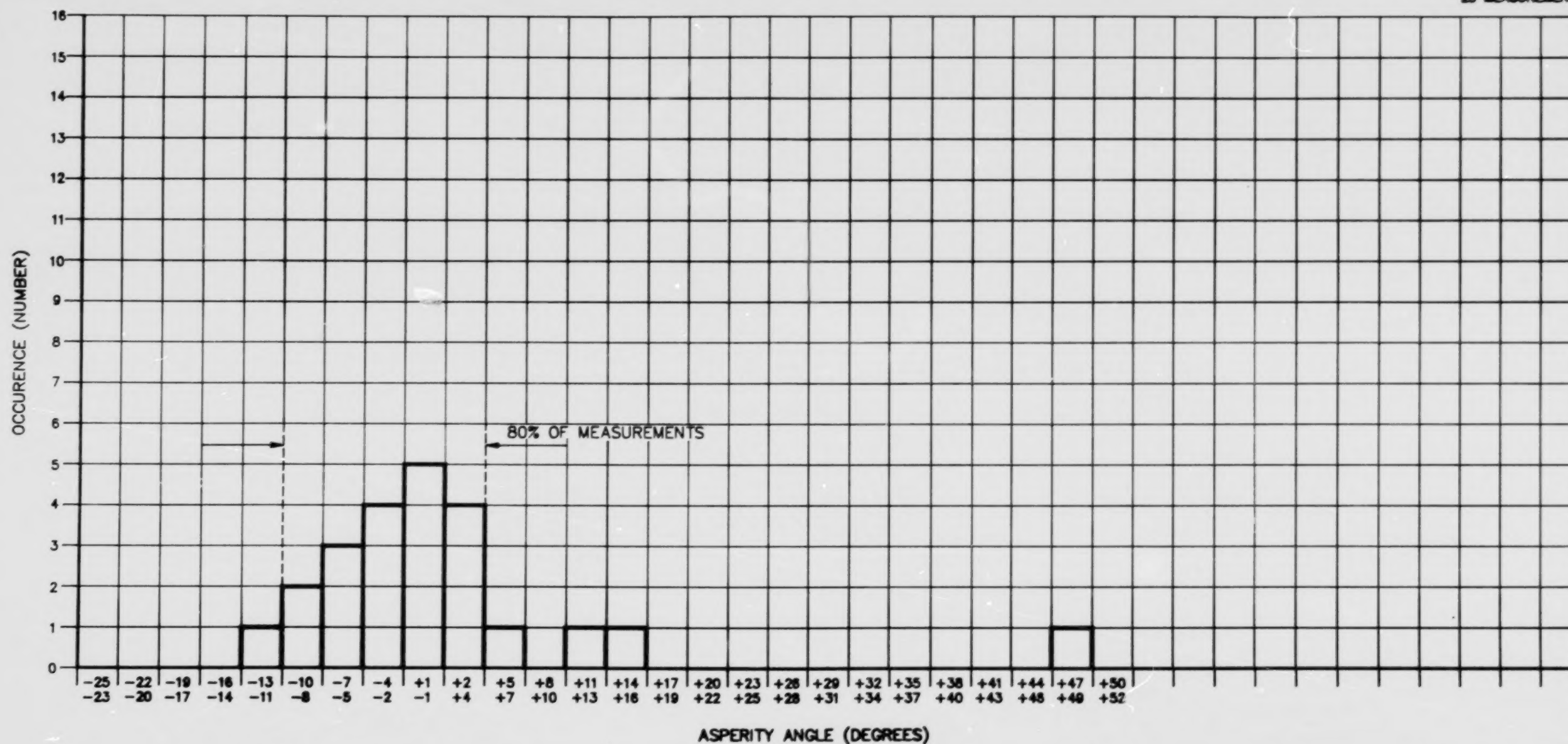
SEAM 3L LOWER SURFACE OF
UPPER ZONE, BASELENGTHS

PLATE B-19



ASPERITY ANGLE VS. BASELENGTH FOR LOWER SURFACE OF UPPER ZONE SEAM 3L

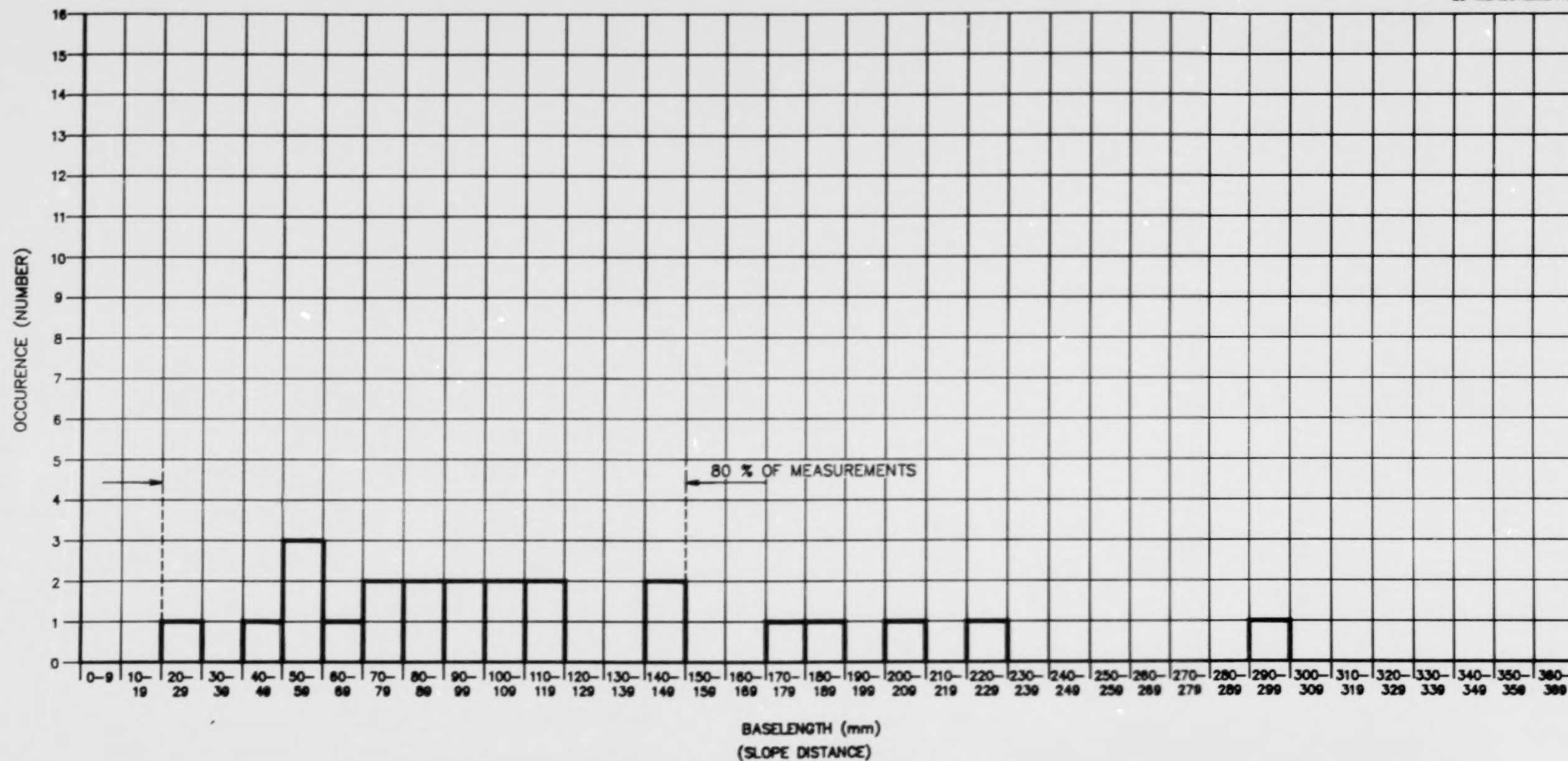
23 MEASUREMENTS



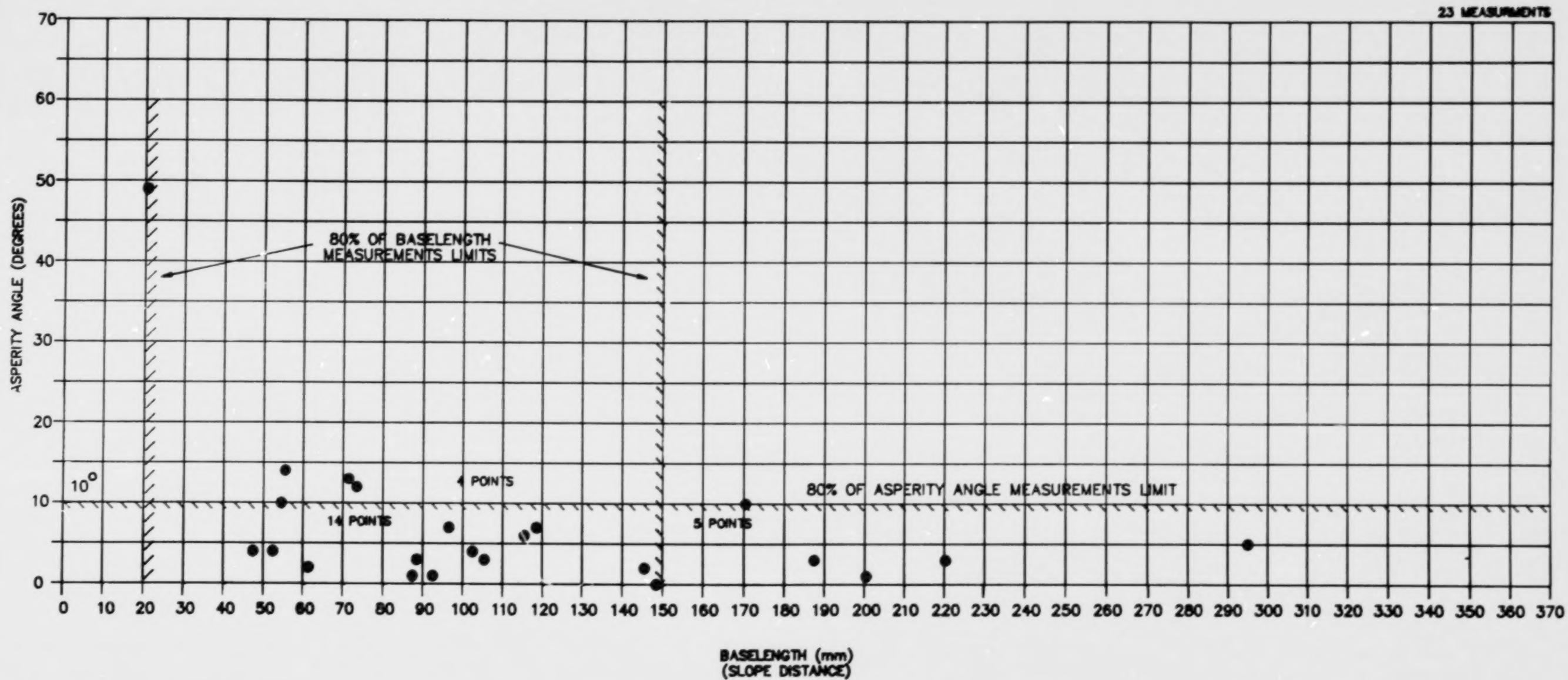
+ ANGLE = WESTERLY DIP
- ANGLE = EASTERLY DIP

HISTOGRAM OF ASPERITY ANGLES ON LOWER WALL ROCK SURFACE SEAM 3U

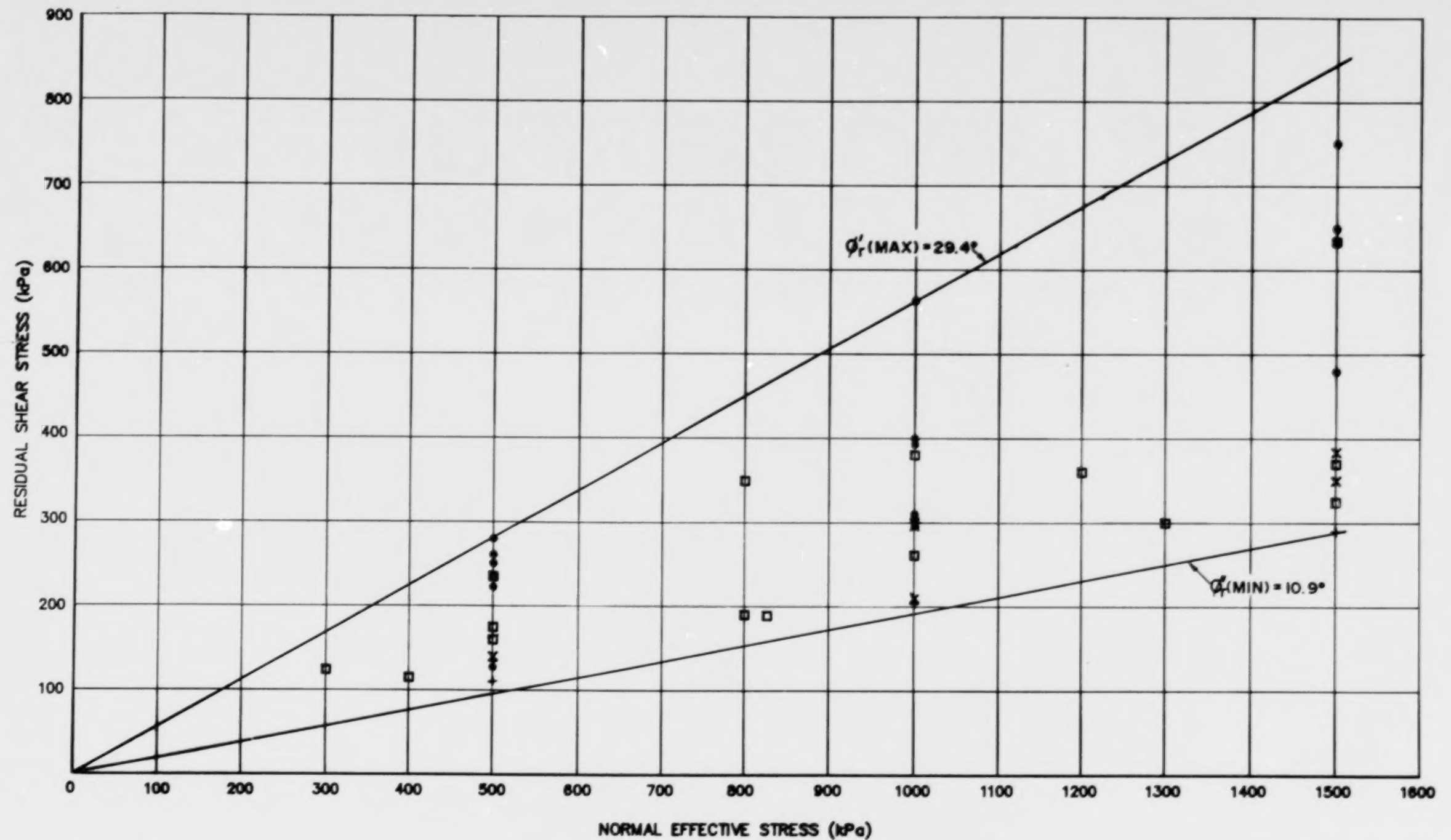
23 MEASUREMENTS



HISTOGRAM OF BASELENGTHS OF LOWER WALL ROCK SURFACE OF SEAM 3U



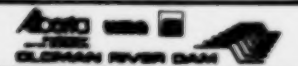
ASPERITY ANGLE VS. BASELENGTH FOR LOWER WALL ROCK SURFACE OF SEAM 3U



LEGEND:

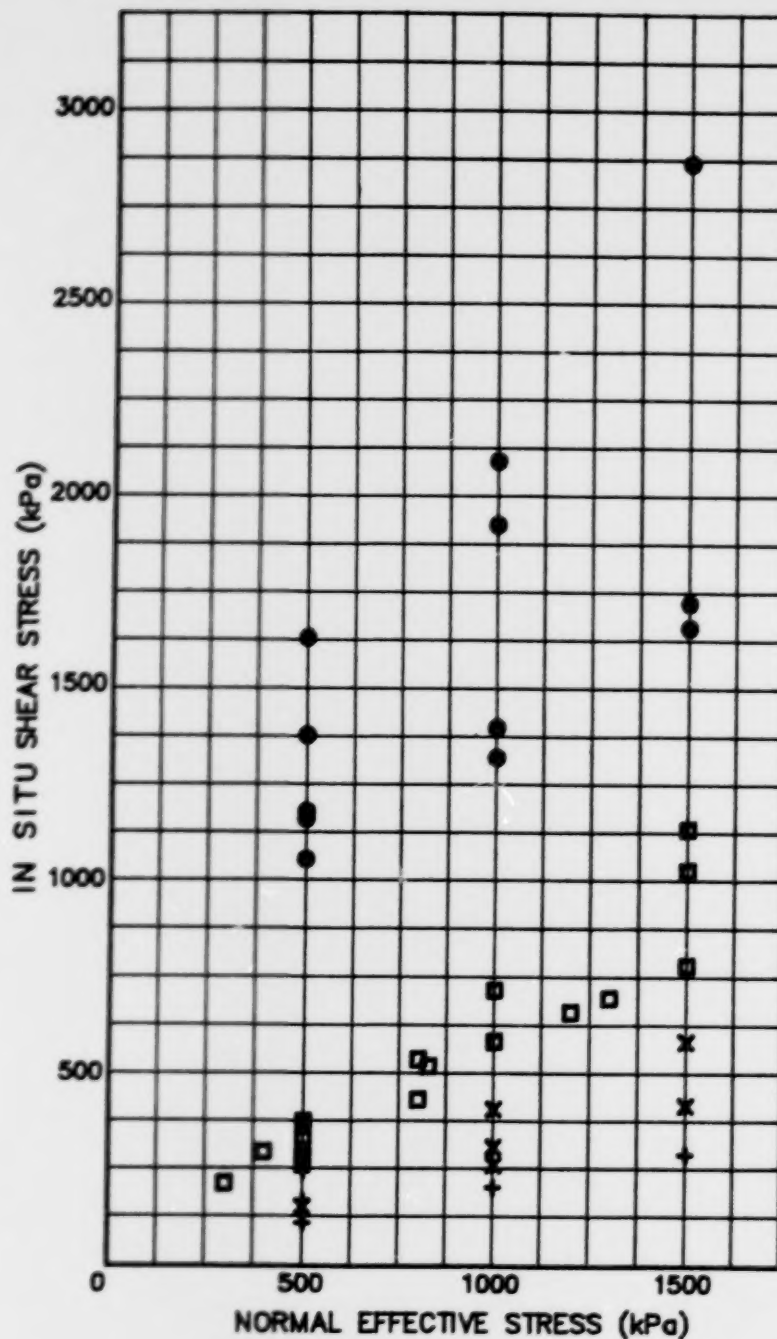
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1mm DURING TEST)

TOTAL NUMBER OF DIRECT SHEAR TESTS = 39



RESIDUAL SHEAR STRENGTH
BELOW ELEVATION 1040m

PLATE B-37

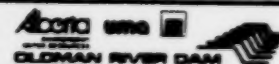


DIRECT SHEAR TEST RESULTS

LEGEND:

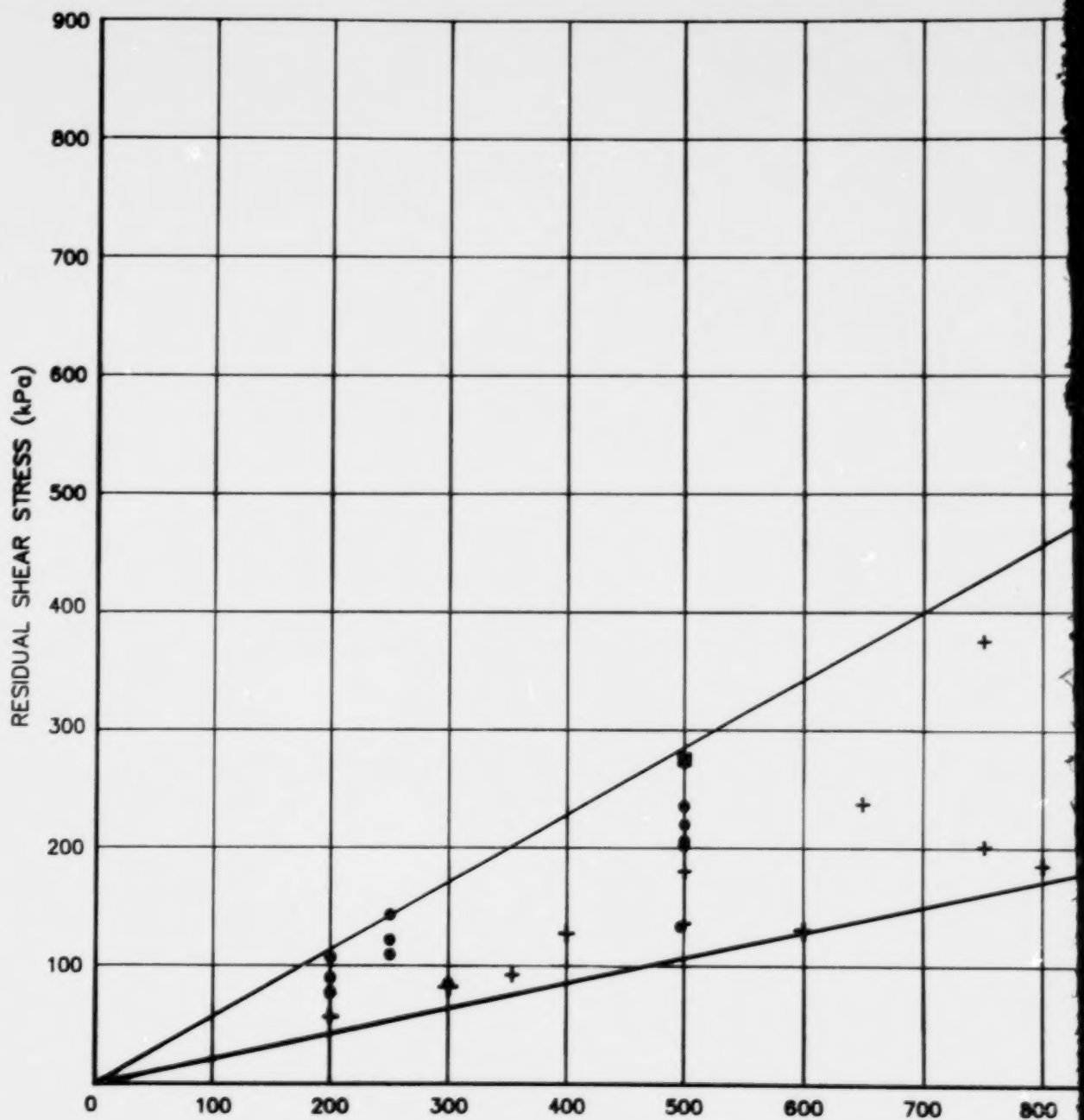
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ± 1 mm DURING TEST)

TOTAL NUMBER OF DIRECT SHEAR TESTS = 39



IN SITU SHEAR STRENGTH
BELOW ELEVATION 1040m

PLATE B - 38

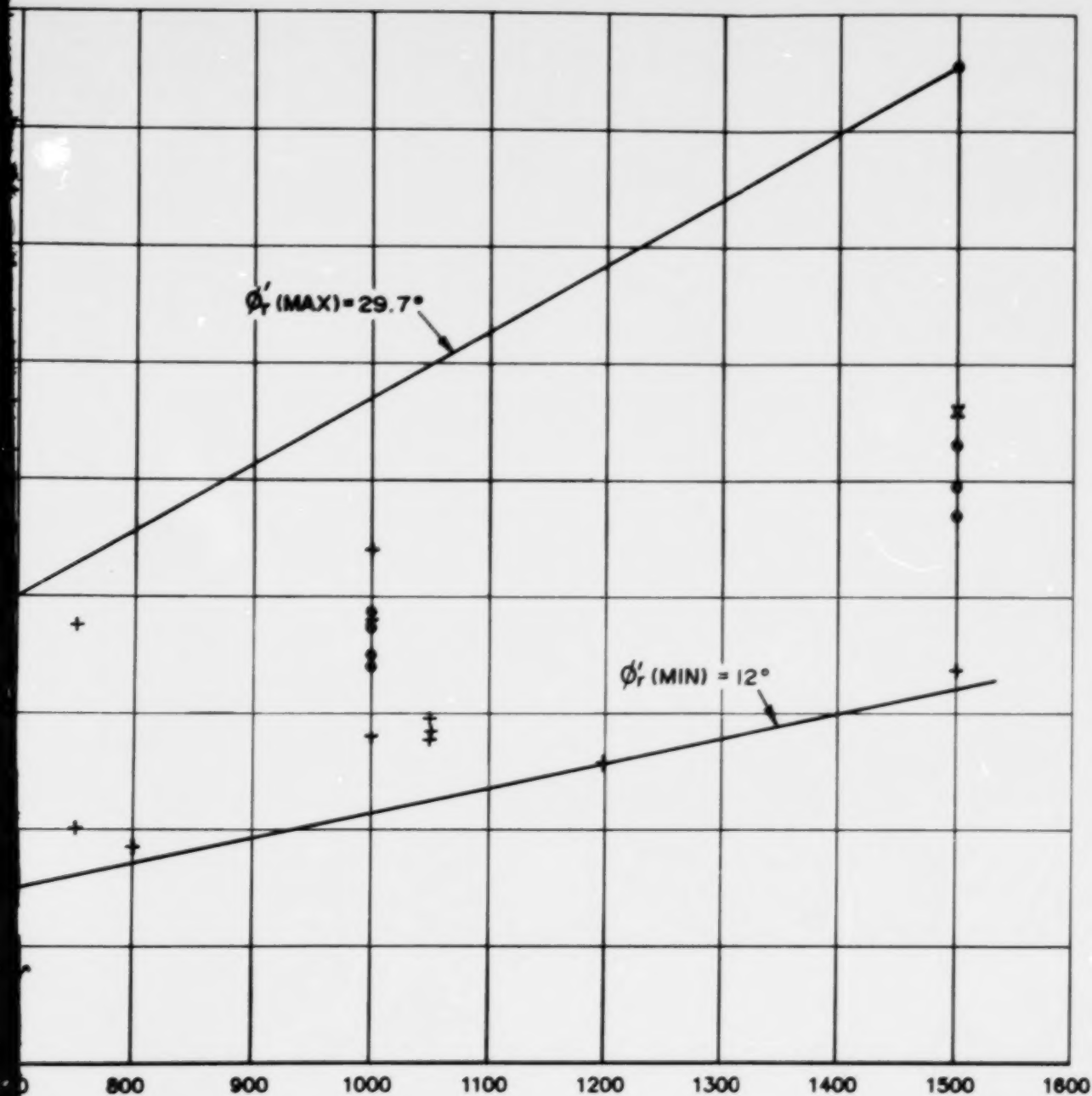


LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1mm DURING TEST)

NORMAL EFFECTIVE STRESS (kPa)

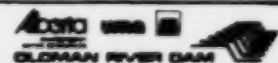
DIRECT SHEAR TEST



EFFECTIVE STRESS (kPa)

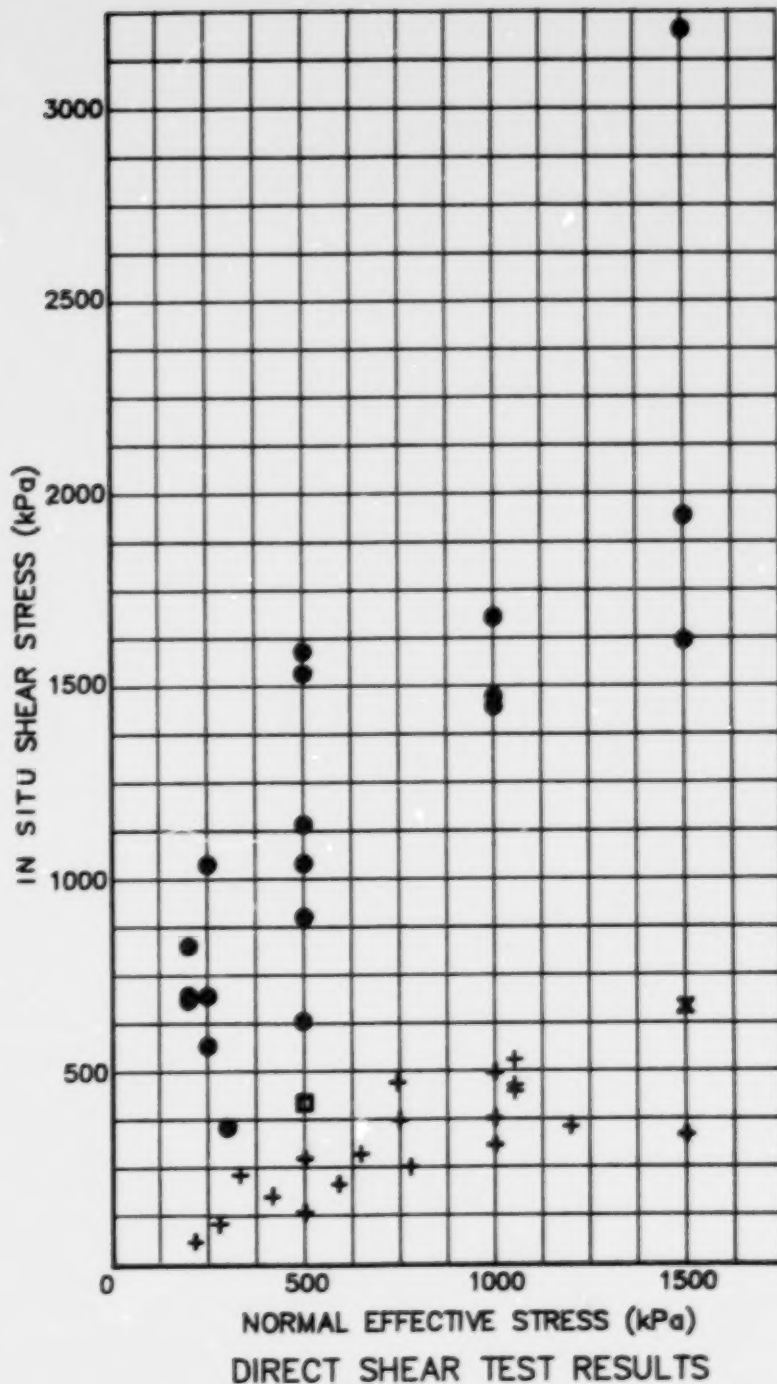
SHEAR TEST RESULTS

TOTAL NUMBER OF DIRECT
SHEAR TESTS = 36



RESIDUAL SHEAR STRENGTH
ELEVATION 1040m to 1050m

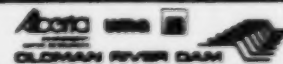
PLATE B-39



LEGEND:

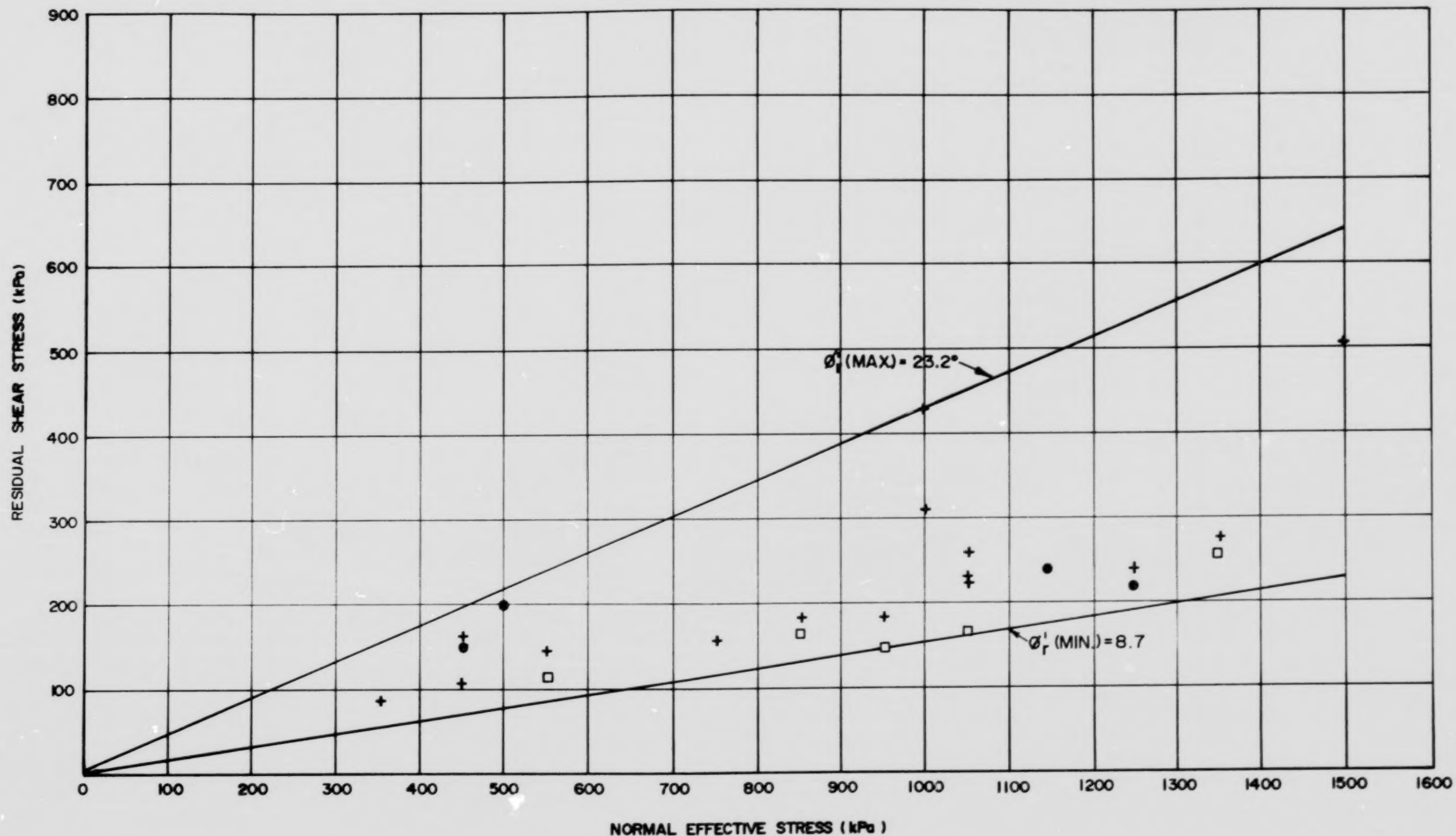
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

TOTAL NUMBER OF DIRECT
SHEAR TESTS = 33



IN SITU SHEAR STRENGTH
ELEVATION 1040m to 1050m

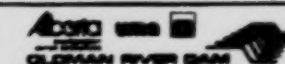
PLATE B-40



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1mm DURING TEST)

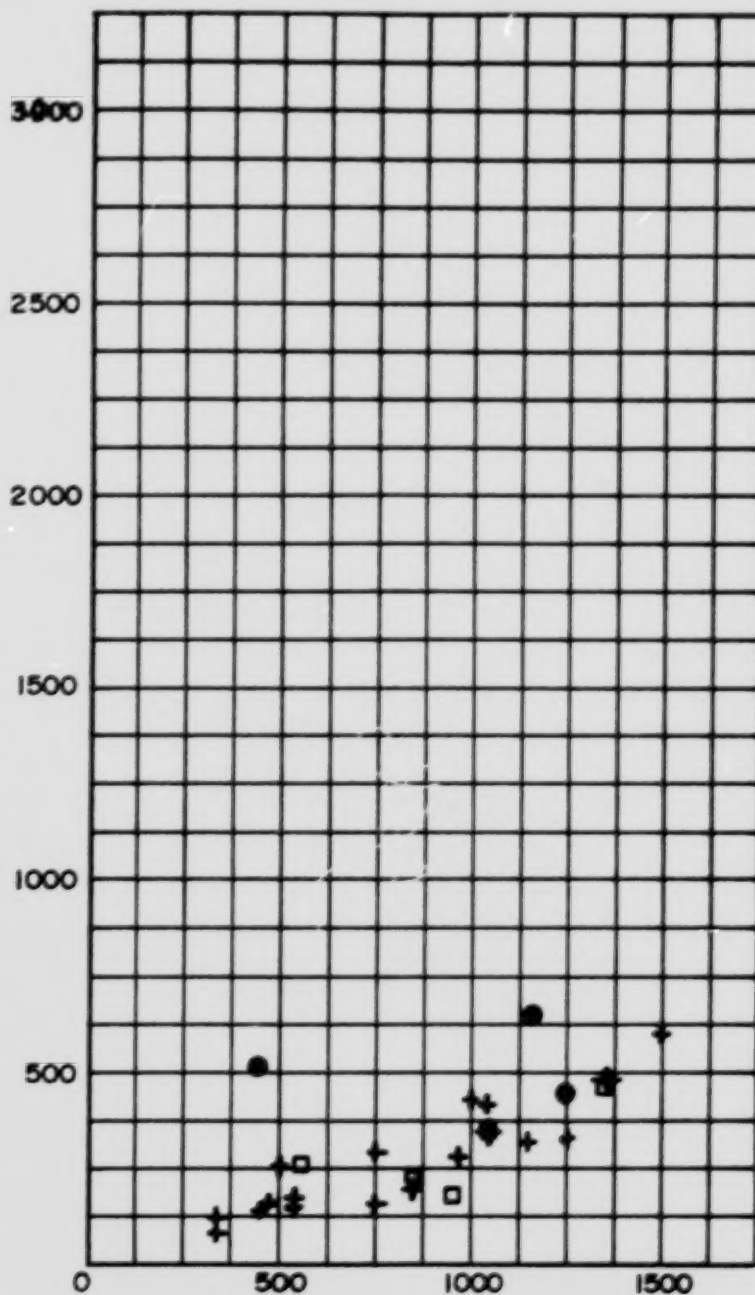
TOTAL NUMBER OF DIRECT SHEAR TESTS = 26



RESIDUAL SHEAR STRENGTH BETWEEN 1050m to 1085m

PLATE B-41

IN SITU SHEAR STRESS (kPa)

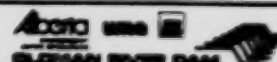


DIRECT SHEAR TEST RESULTS

LEGEND:

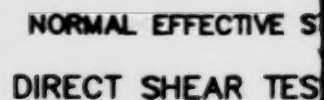
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- X - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1mm DURING TEST)

TOTAL NUMBER OF DIRECT SHEAR TESTS = 26

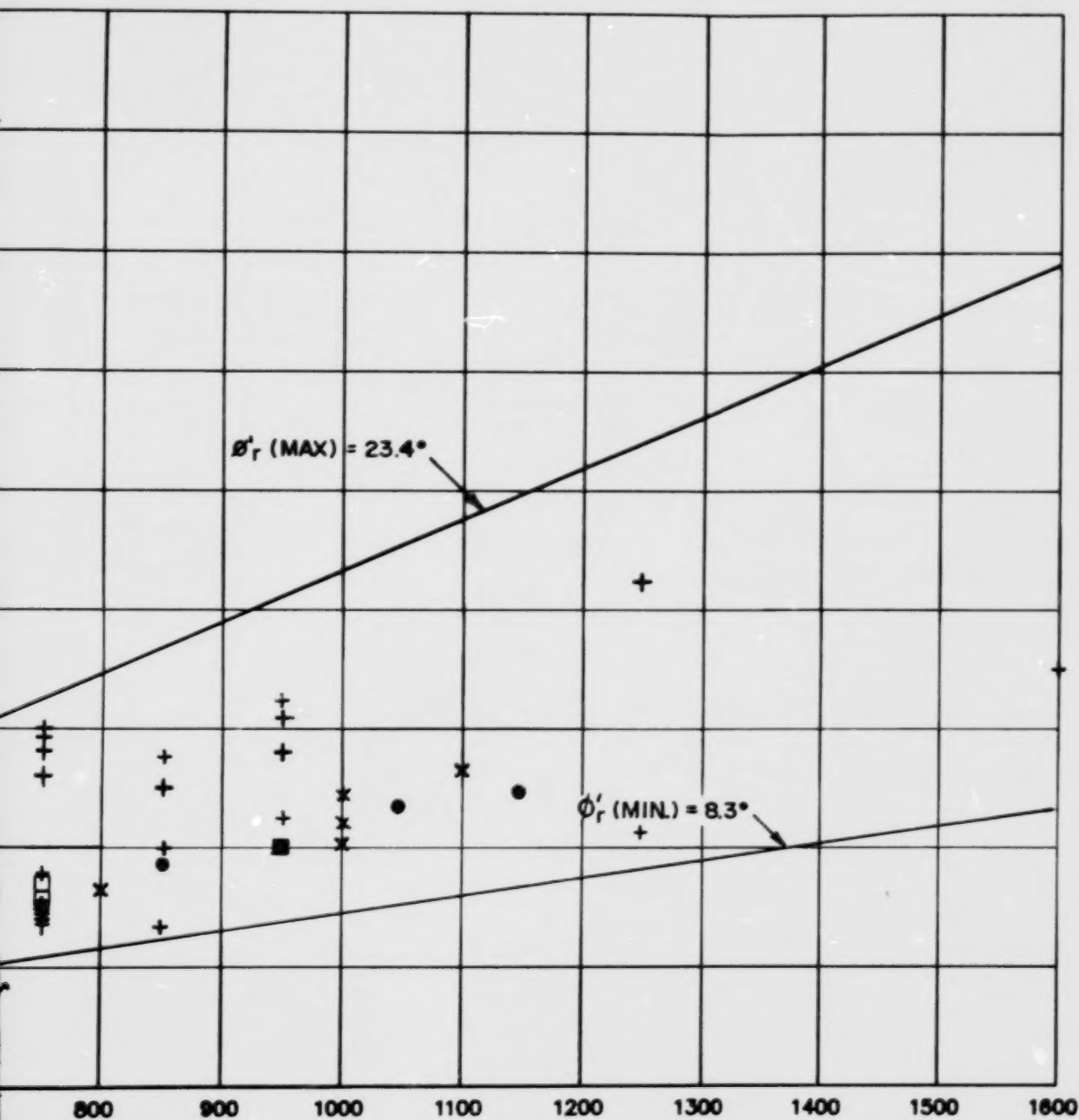


IN SITU SHEAR STRENGTH
ELEVATION 1050m to 1085m

PLATE B-42



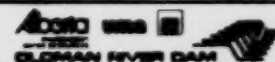
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- X - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



EFFECTIVE STRESS (kPa)

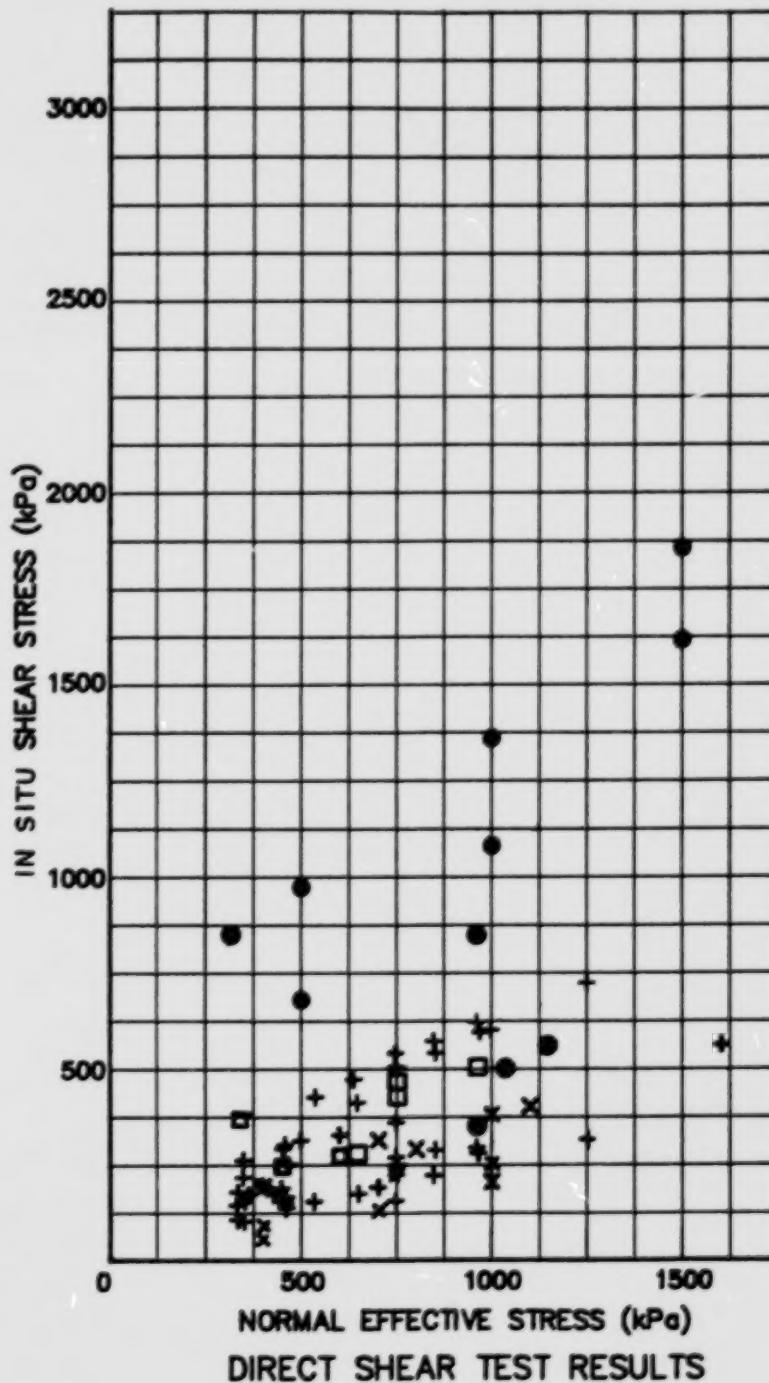
SHEAR TEST RESULTS

TOTAL NUMBER OF DIRECT
SHEAR TESTS = 67



RESIDUAL SHEAR STRENGTH
ELEVATION 1085m to 1090m

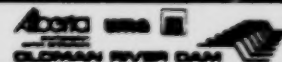
PLATE B-43



LEGEND:

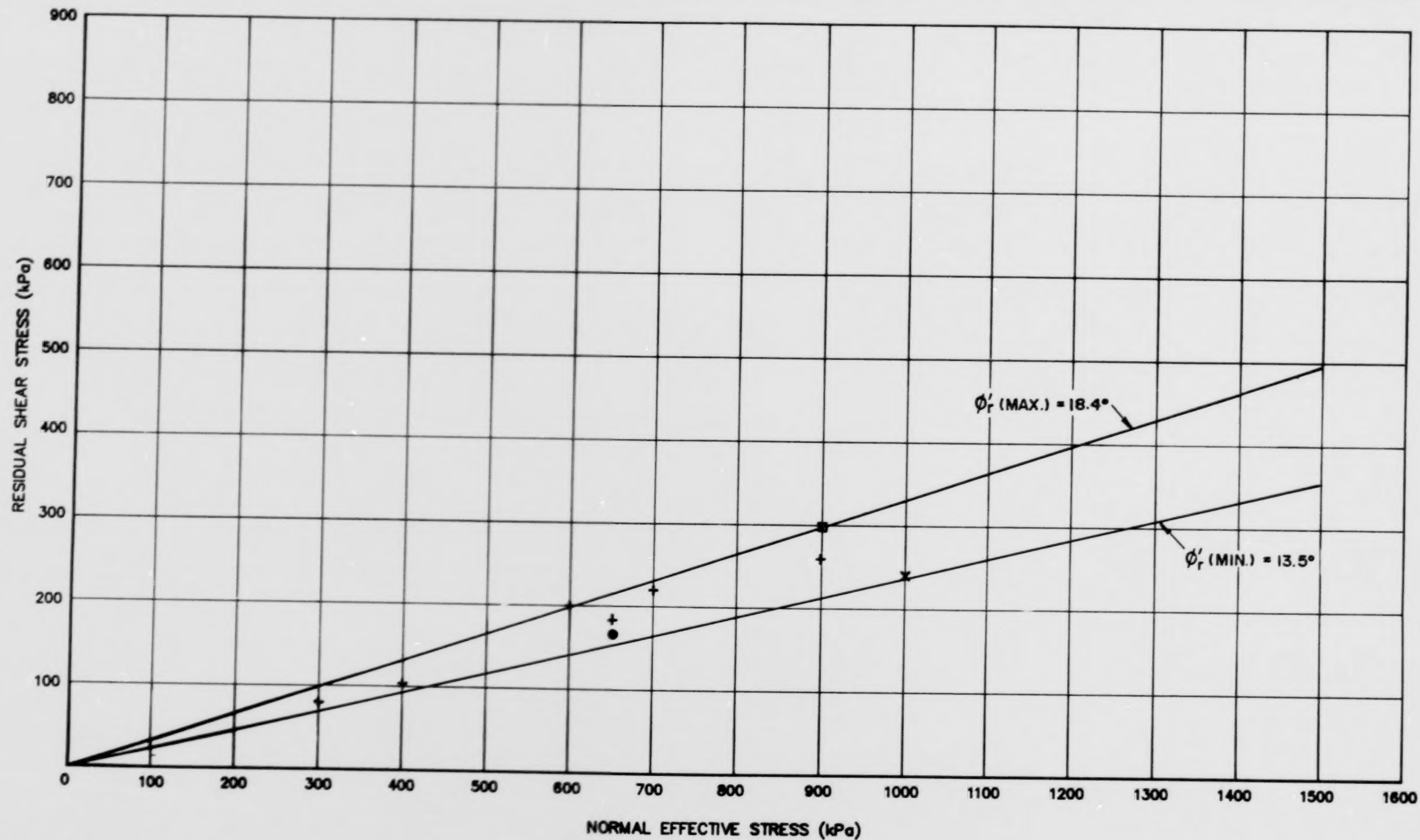
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED $\approx$ 1mm DURING TEST)

**TOTAL NUMBER OF DIRECT
SHEAR TESTS = 67**



**IN SITU SHEAR STRENGTH
ELEVATIONS 1085m to 1090m**

PLATE B-44

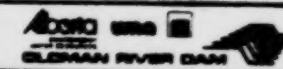


LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- ×
- SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED 3 mm DURING TEST)

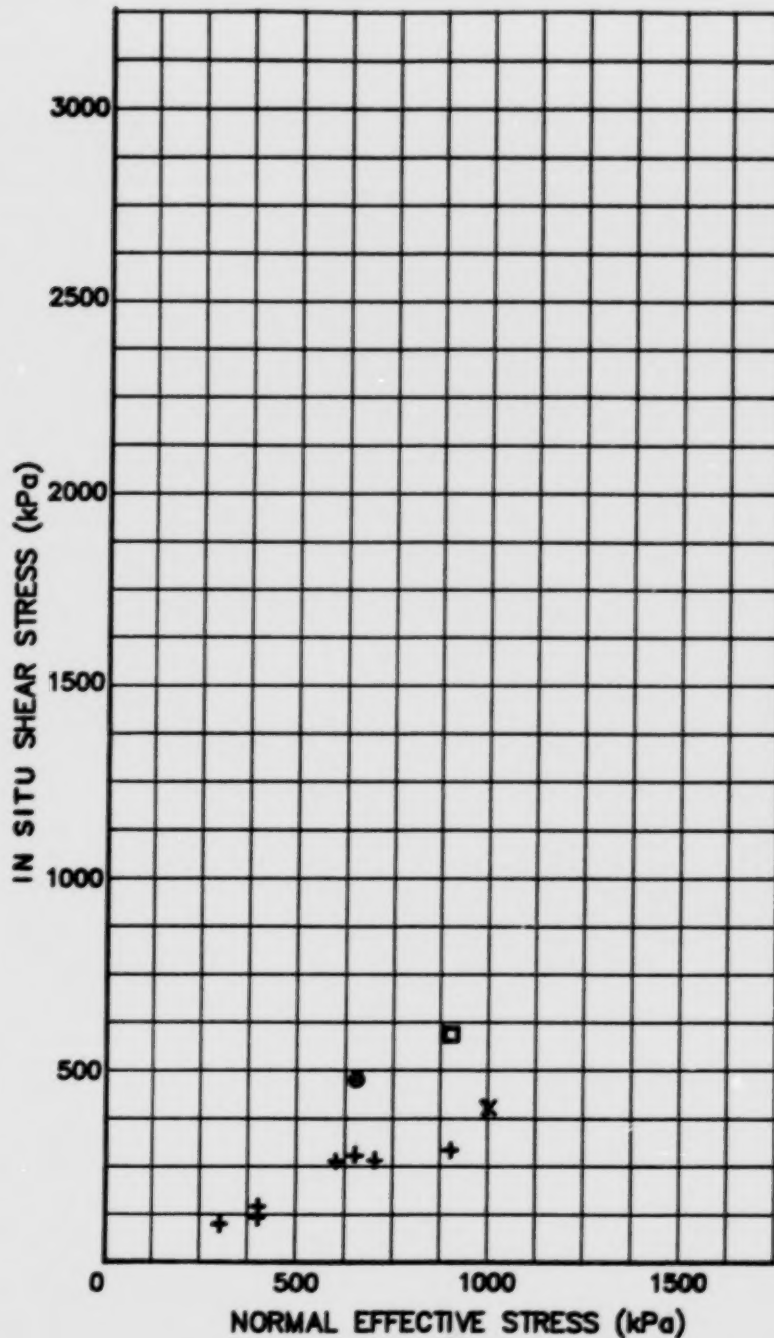
DIRECT SHEAR TEST RESULTS

TOTAL NUMBER OF DIRECT SHEAR TESTS = 10



RESIDUAL SHEAR STRENGTH
ELEVATION 1090m to 1100m

PLATE B - 45

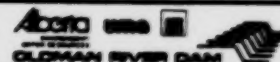


DIRECT SHEAR TEST RESULTS

LEGEND:

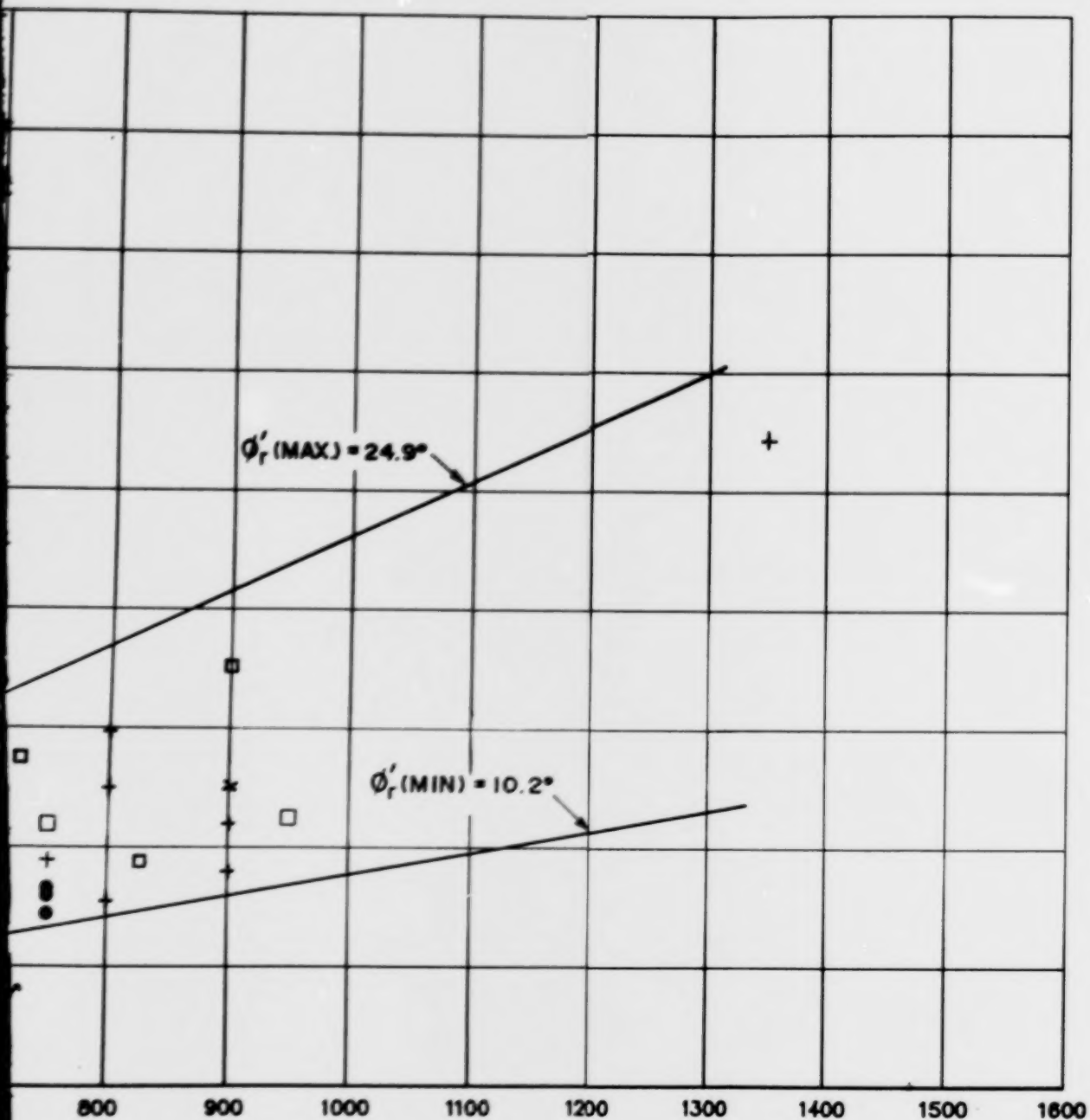
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED $\pm$ 1mm DURING TEST)

TOTAL NUMBER OF DIRECT
SHEAR TESTS = 10



IN SITU SHEAR STRENGTH
ELEVATIONS 1090m to 1100m

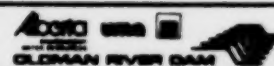
PLATE B-46



EFFECTIVE STRESS (kPa)

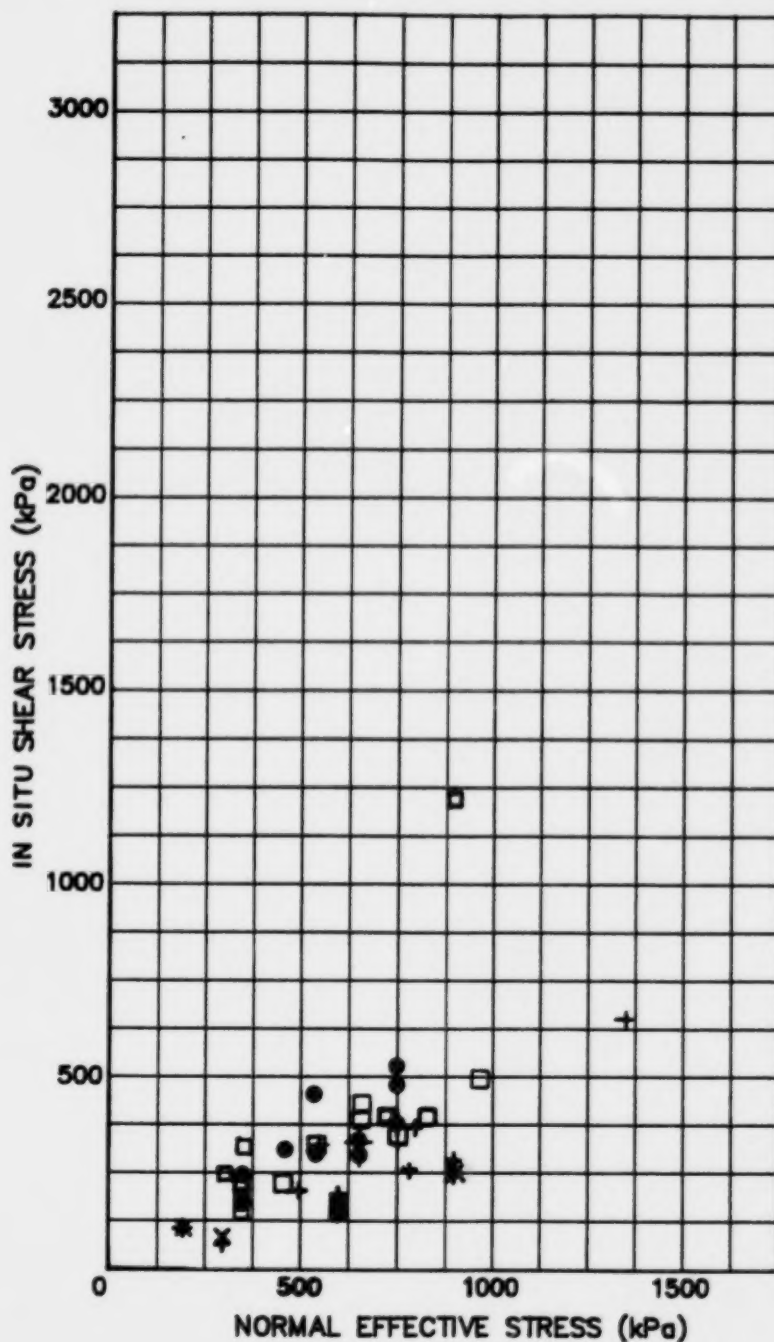
SHEAR TEST RESULTS

TOTAL NUMBER OF DIRECT
SHEAR TESTS = 46



RESIDUAL SHEAR STRENGTH
ABOVE ELEVATION 1100m

PLATE B-47



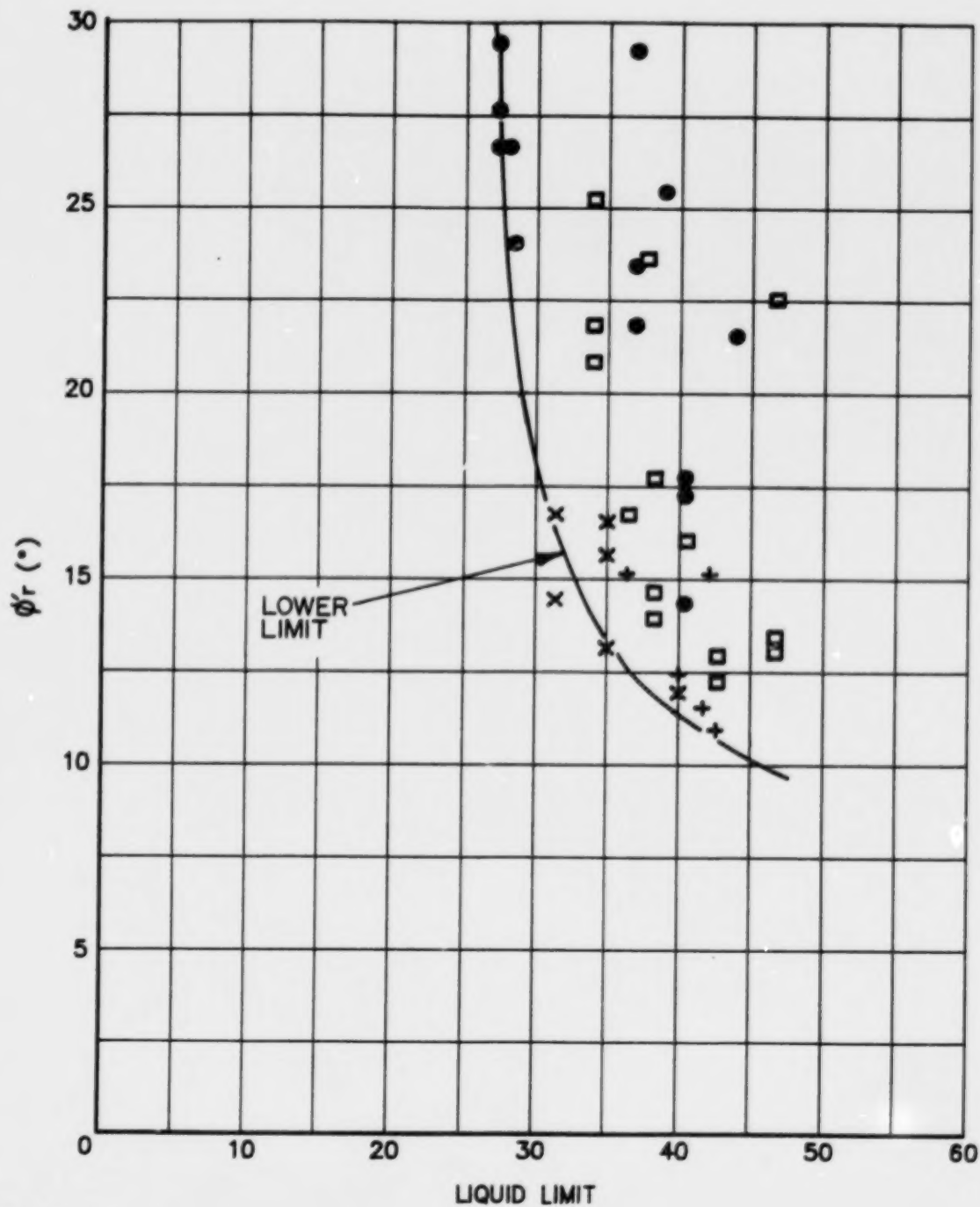
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ± 1 mm DURING TEST)

DIRECT SHEAR TEST RESULTS

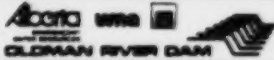
TOTAL NUMBER OF DIRECT
SHEAR TESTS = 45

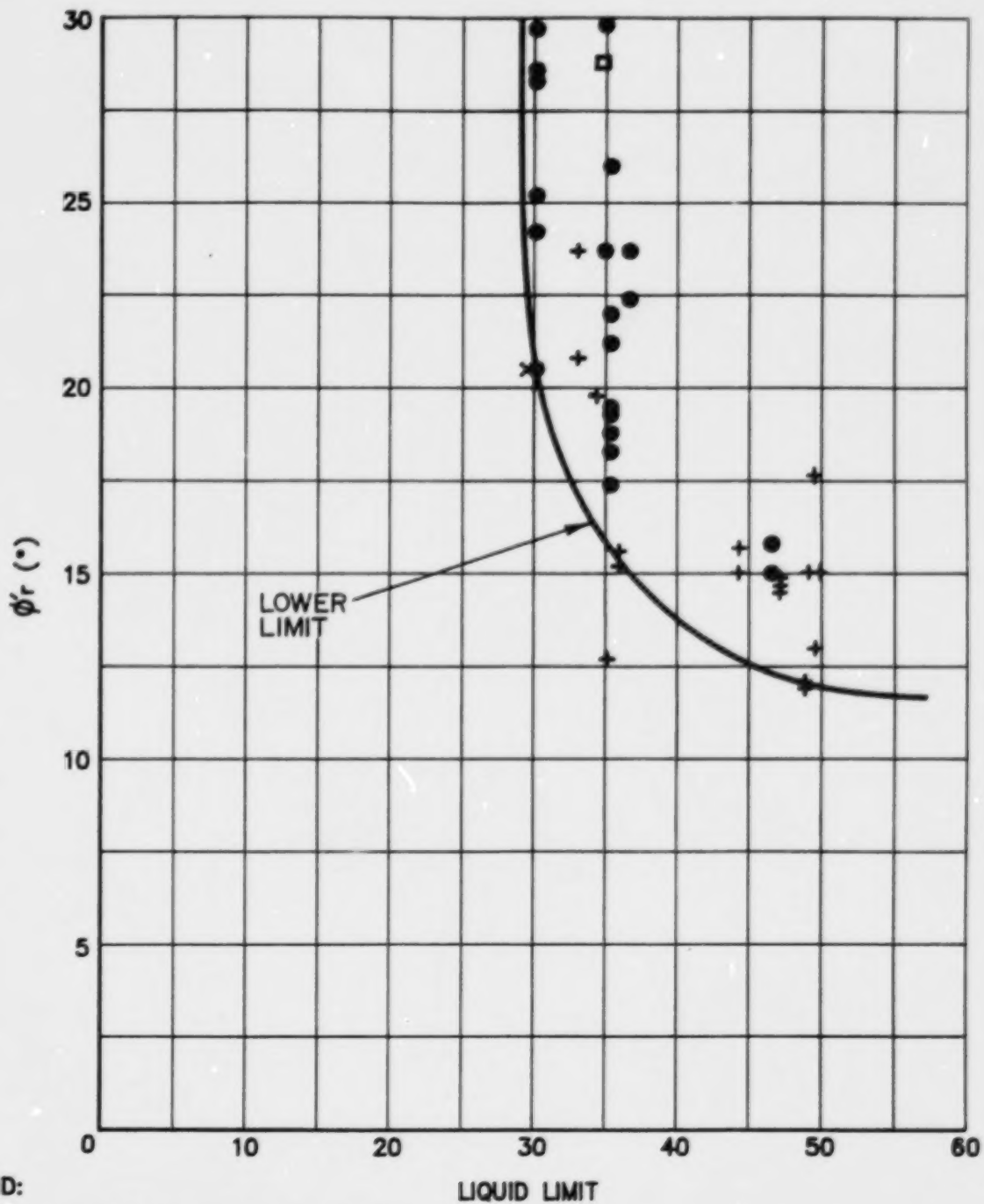
   
IN SITU SHEAR STRENGTH ABOVE ELEVATION 1100m
PLATE B-48



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED $\geq$ 1mm DURING TEST)

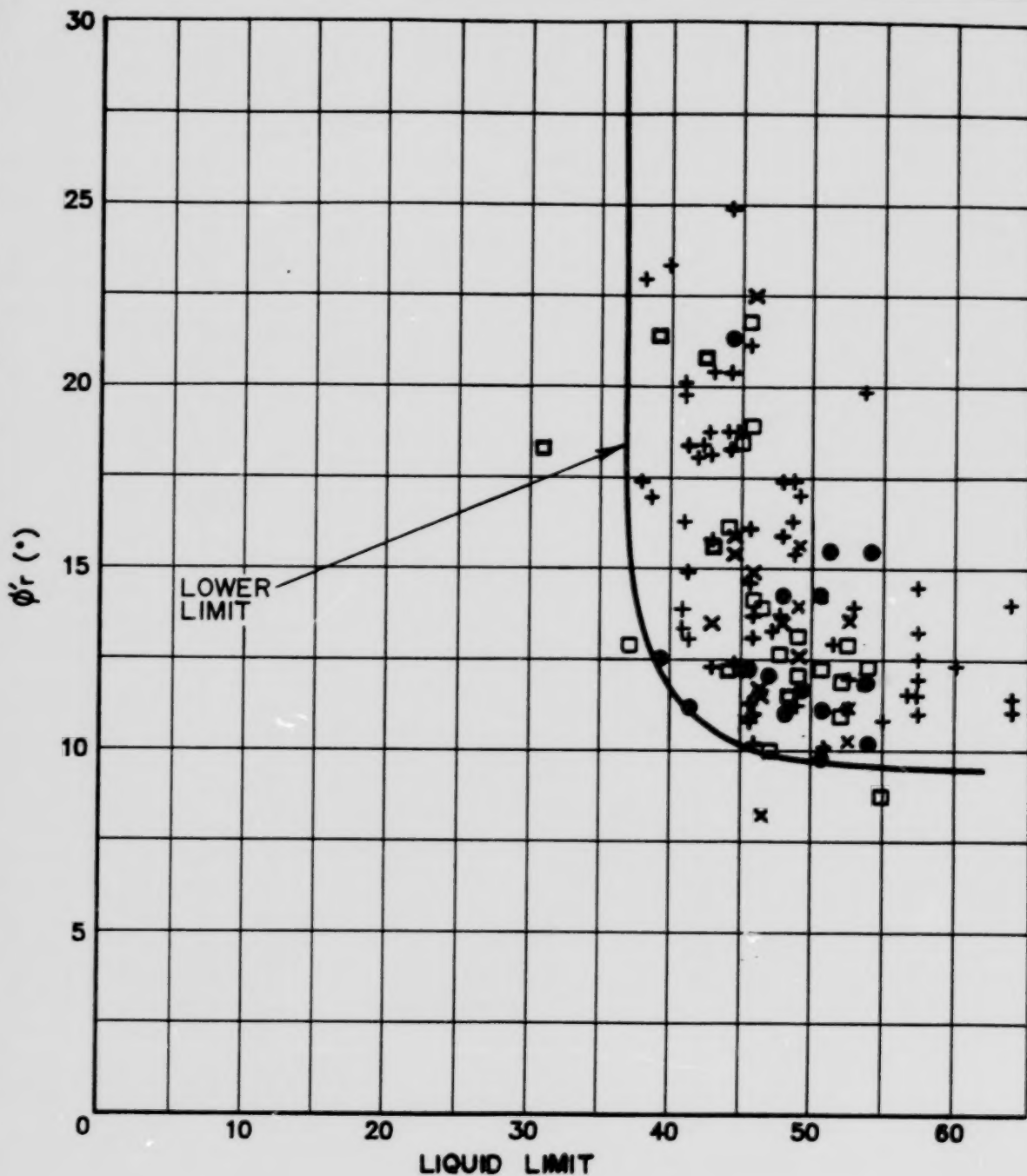

ϕ_r VS LIQUID LIMIT ELEVATION BELOW 1040m
PLATE B-49



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

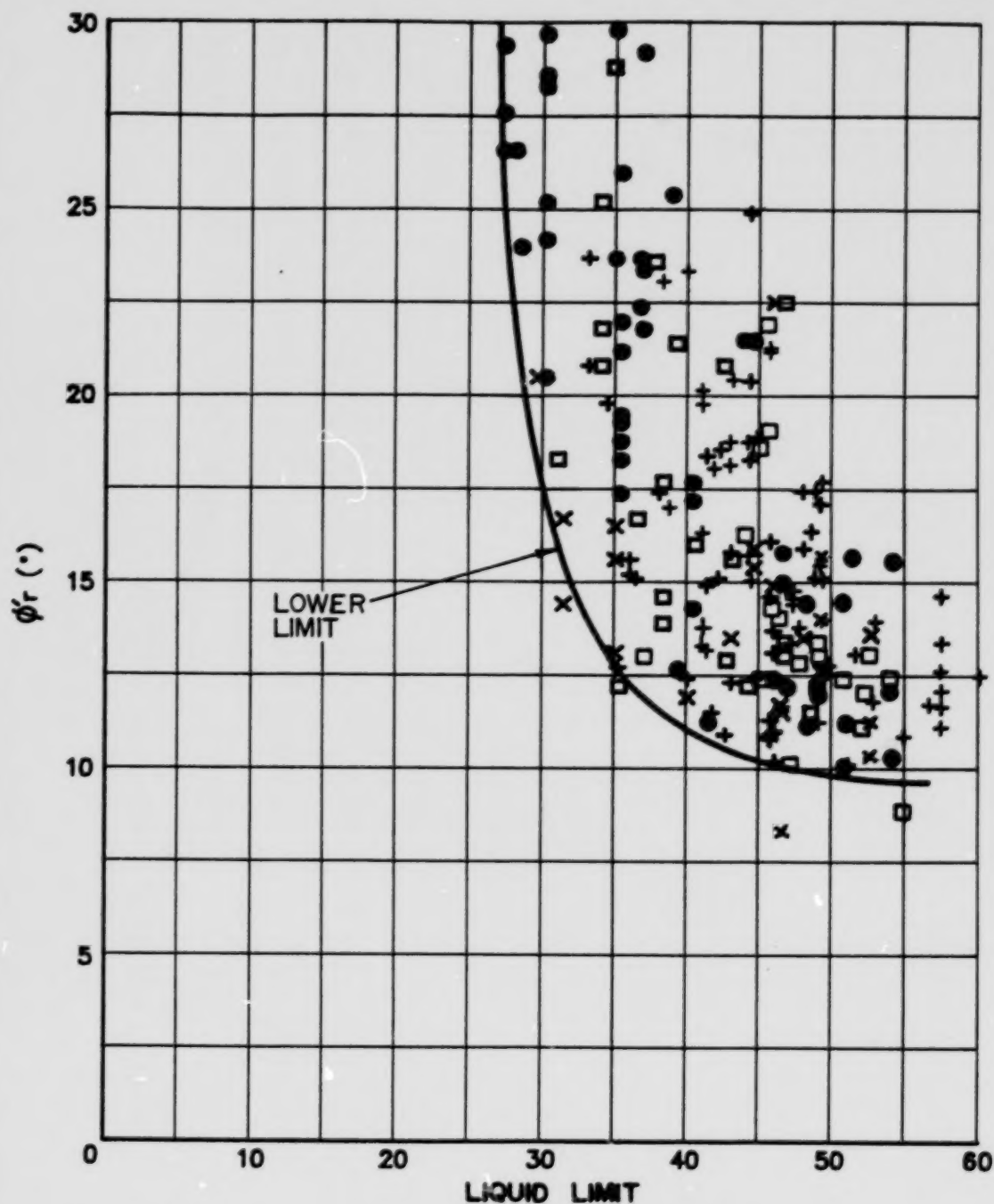
  
ϕ_r VS LIQUID LIMIT ELEVATION 1040m to 1050m
PLATE B-50



LEGEND:

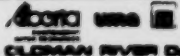
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

ϕ_r VS LIQUID LIMIT ELEVATION ABOVE 1050m
PLATE B-51



LEGEND:

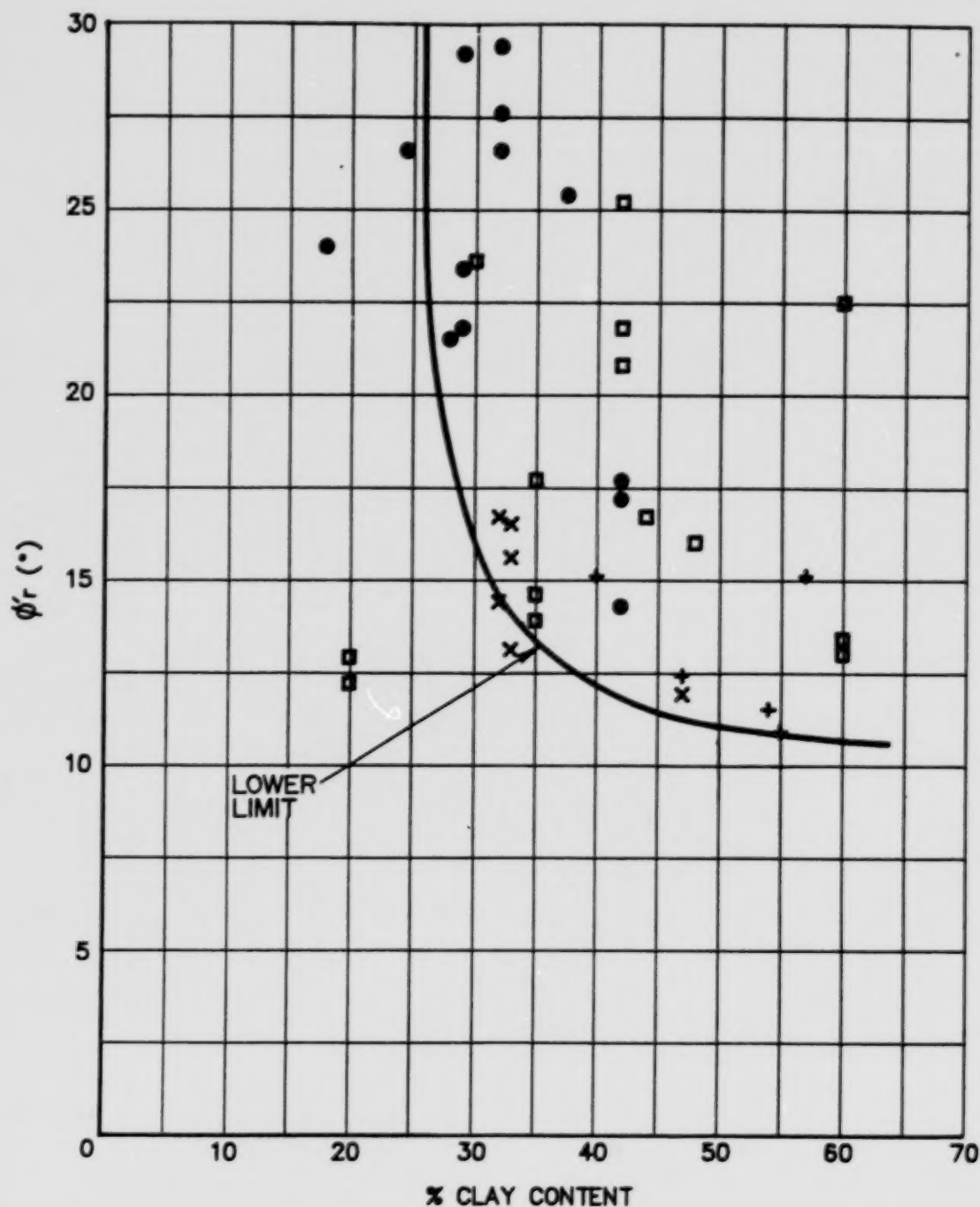
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)




CLERMONT RIVER DAM

ϕ_r VS LIQUID LIMIT
ALL COMBINED

PLATE B-52

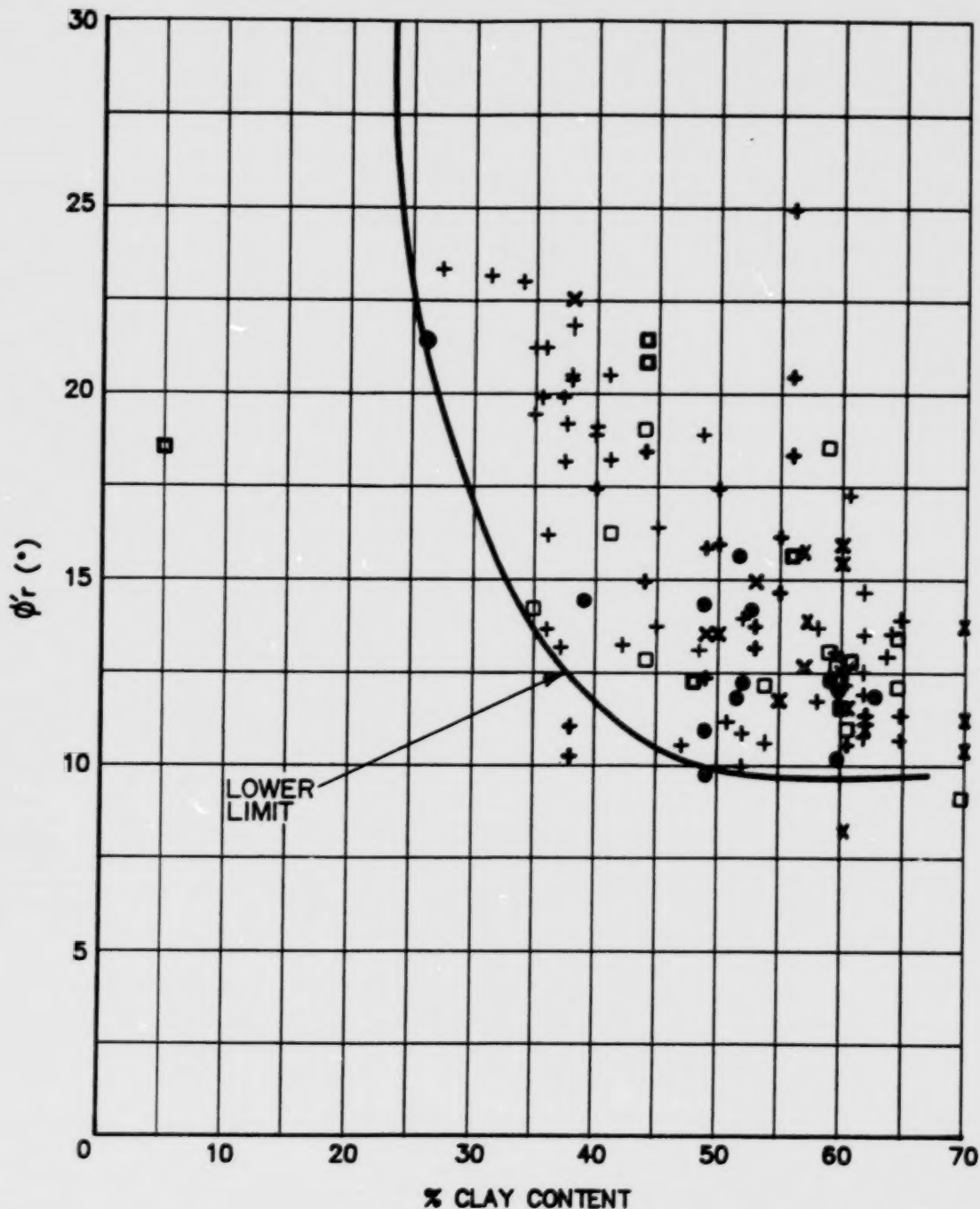


LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED $\geq$ 1mm DURING TEST)

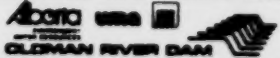
ϕ_r VS CLAY CONTENT
ELEVATION BELOW 1040m

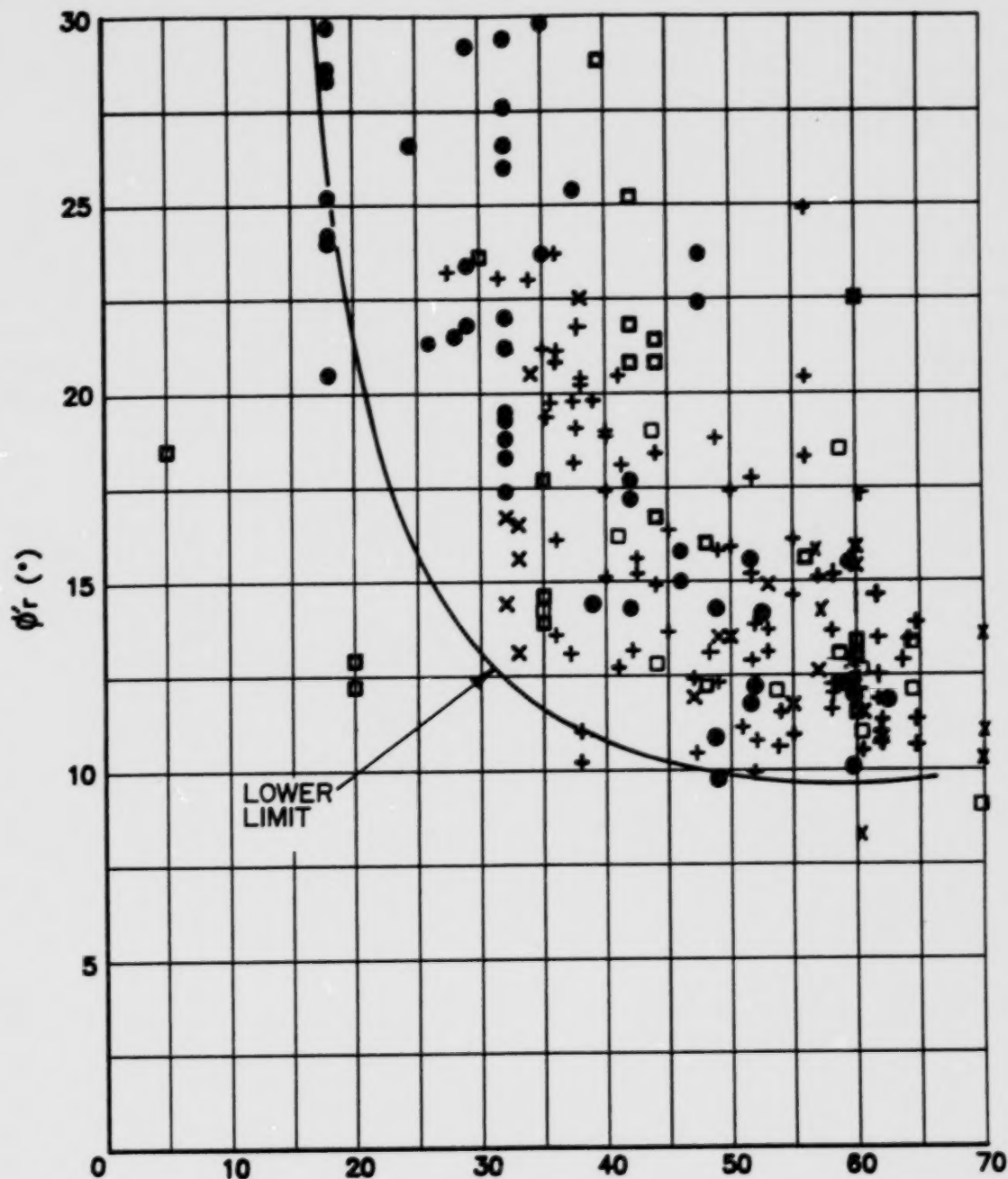
PLATE B-53



LEGEND:

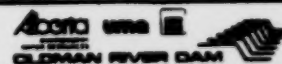
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1mm DURING TEST)

 ADCO INCORPORATED GLEMAN RIVER DAM
φ_r VS CLAY CONTENT ELEVATION ABOVE 1050m
PLATE B-55

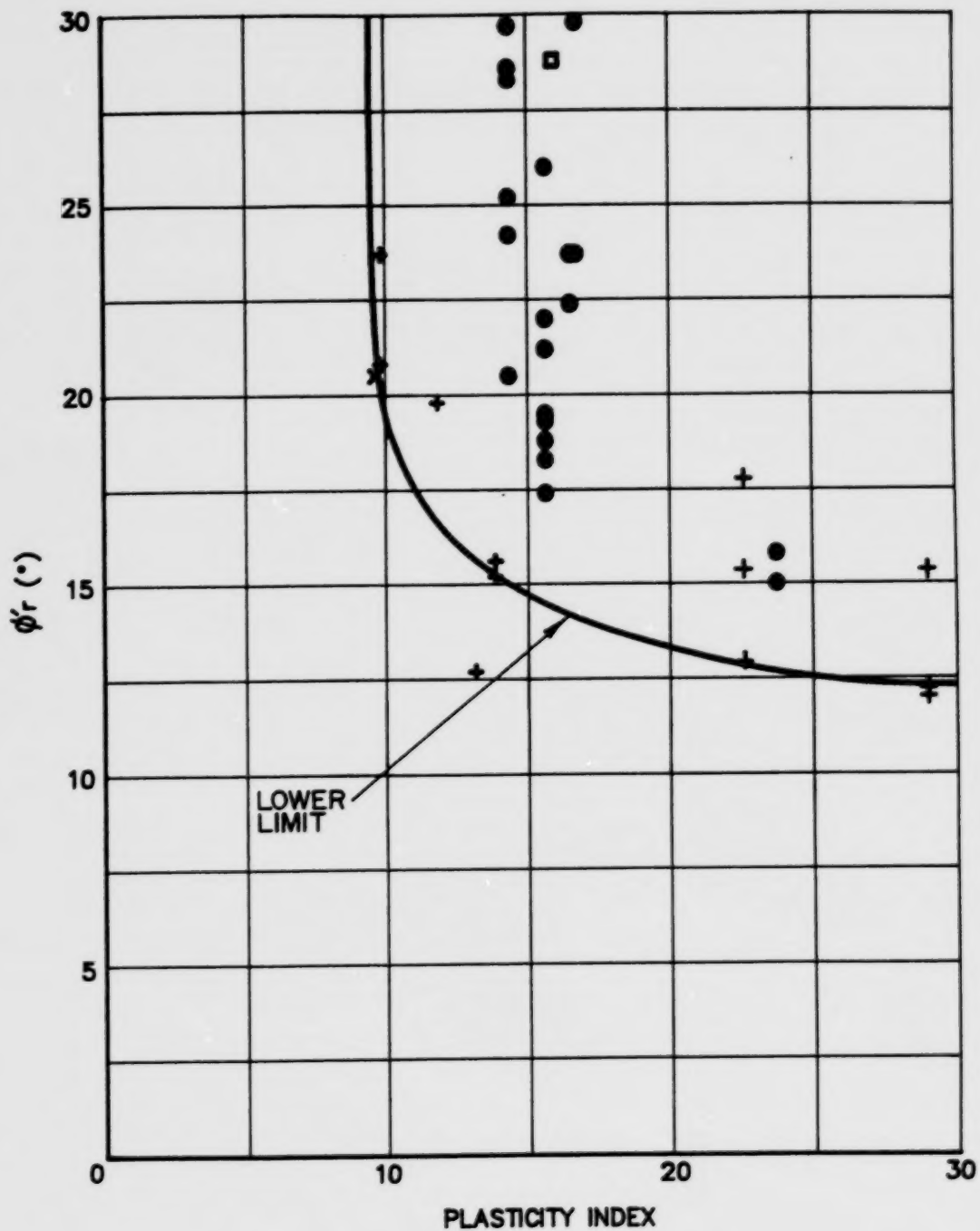


LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED $\geq$ 1mm DURING TEST)

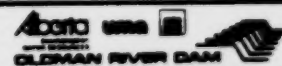


ϕ_r VS CLAY CONTENT
ALL COMBINED



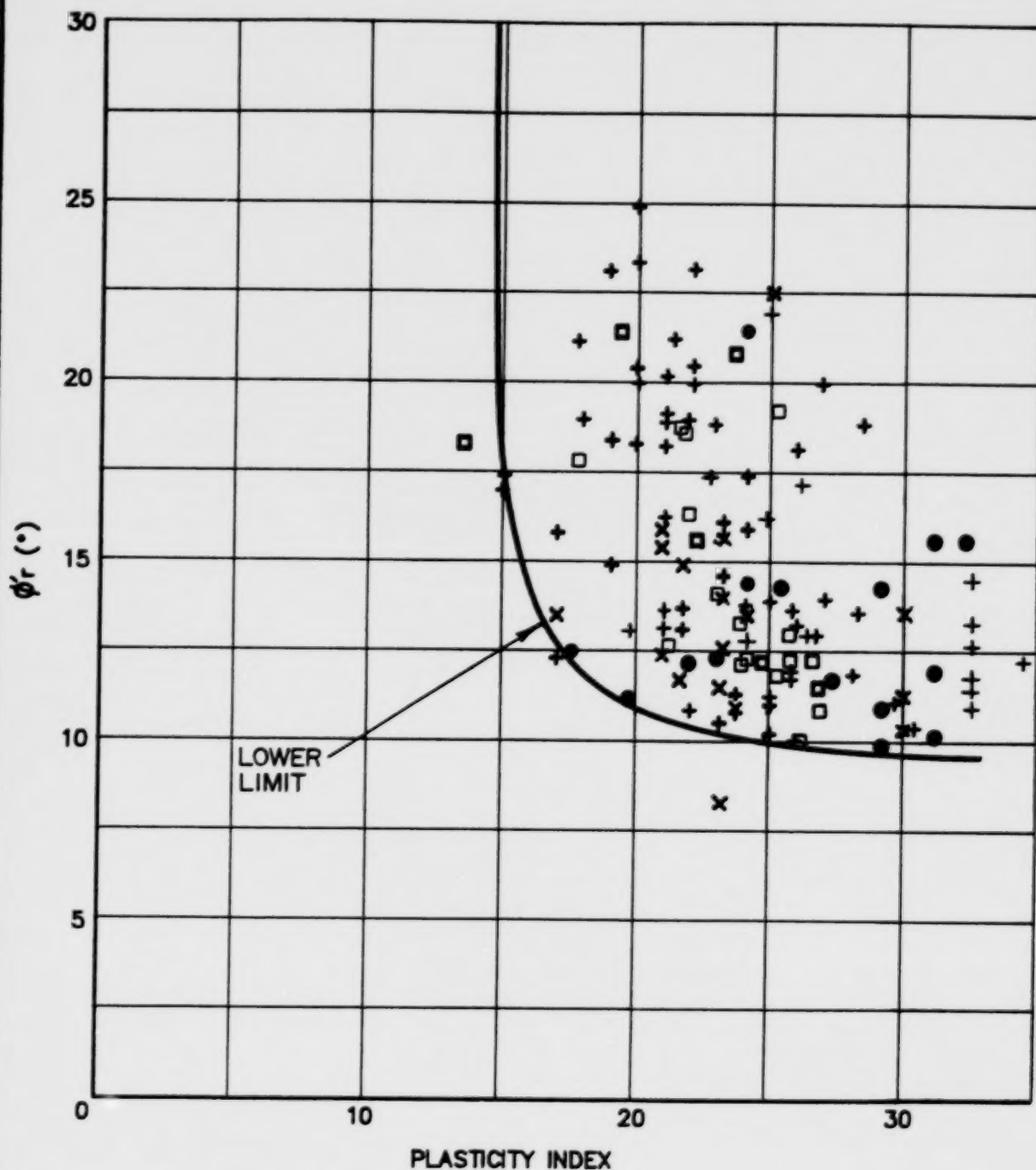
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- +
- SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- X - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



ϕ_r VS PLASTICITY INDEX
ELEVATION 1040 m to 1050 m

PLATE B-58

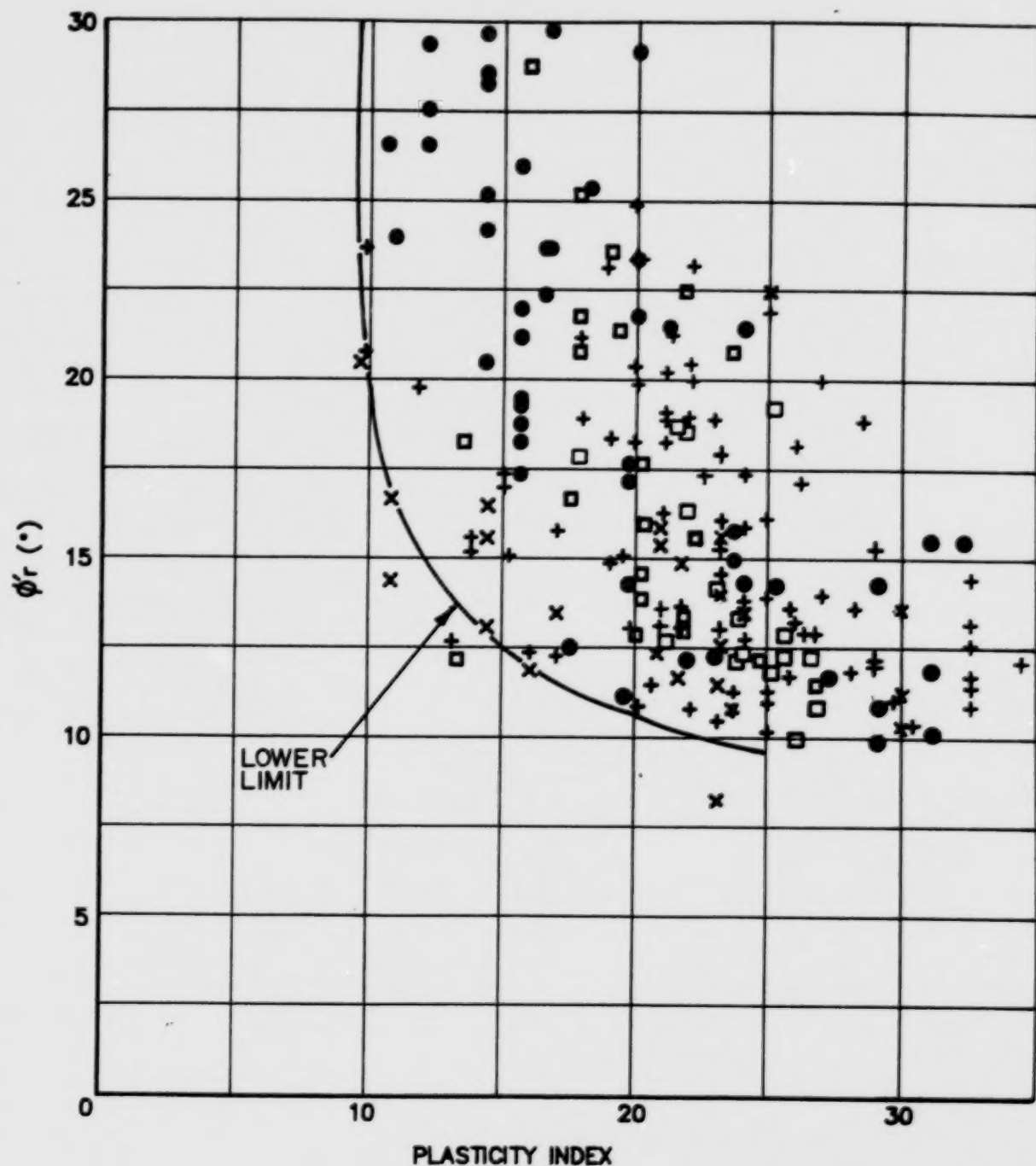


LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1mm DURING TESTS)

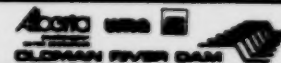
φ_r VS PLASTICITY INDEX
ELEVATION ABOVE 1050m

PLATE B-59



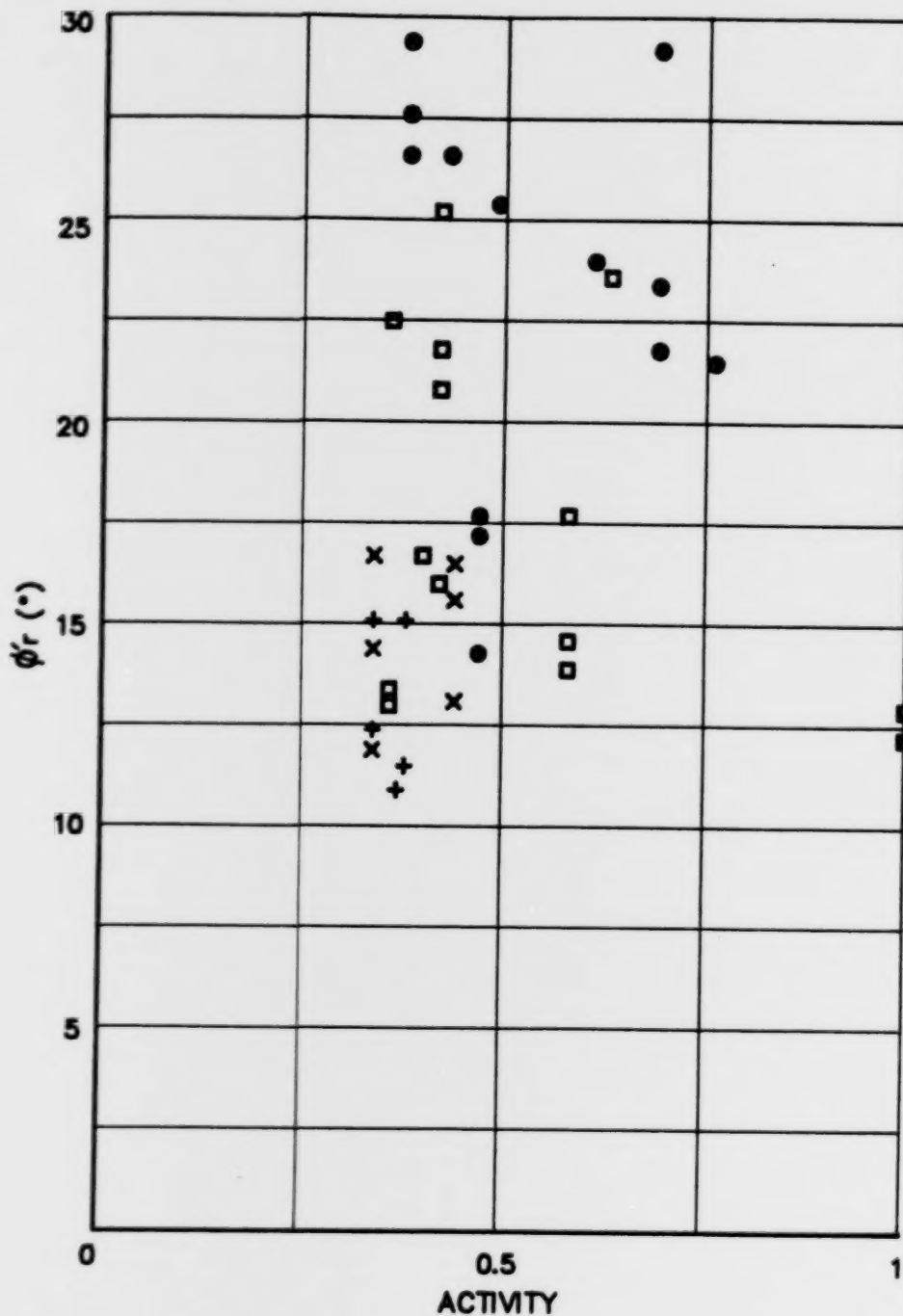
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED $\geq$ 1mm DURING TEST)



ϕ_r VS PLASTICITY INDEX
ALL COMBINED

PLATE B-60

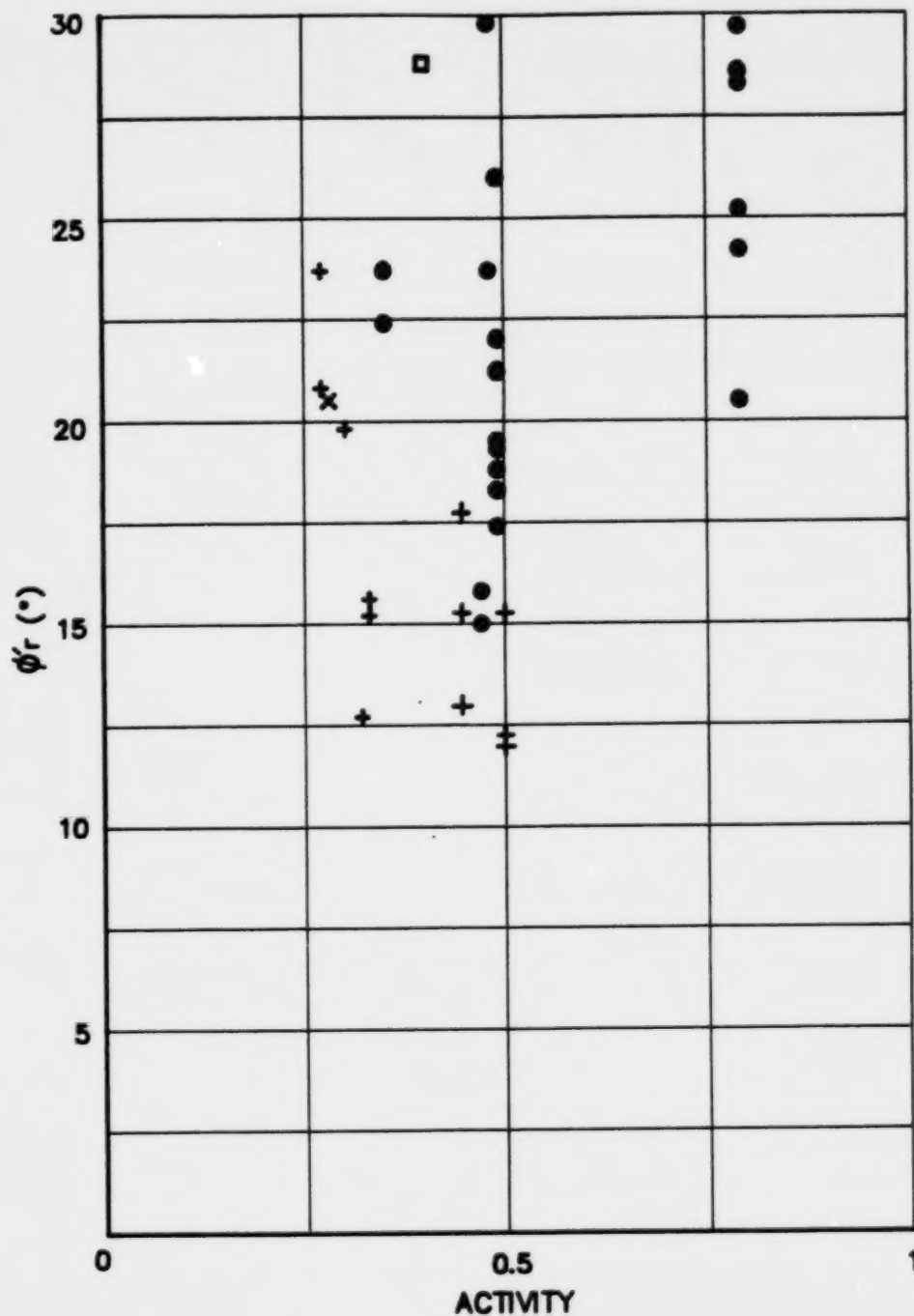


LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

ϕ_r VS ACTIVITY
ELEVATION BELOW 1040m

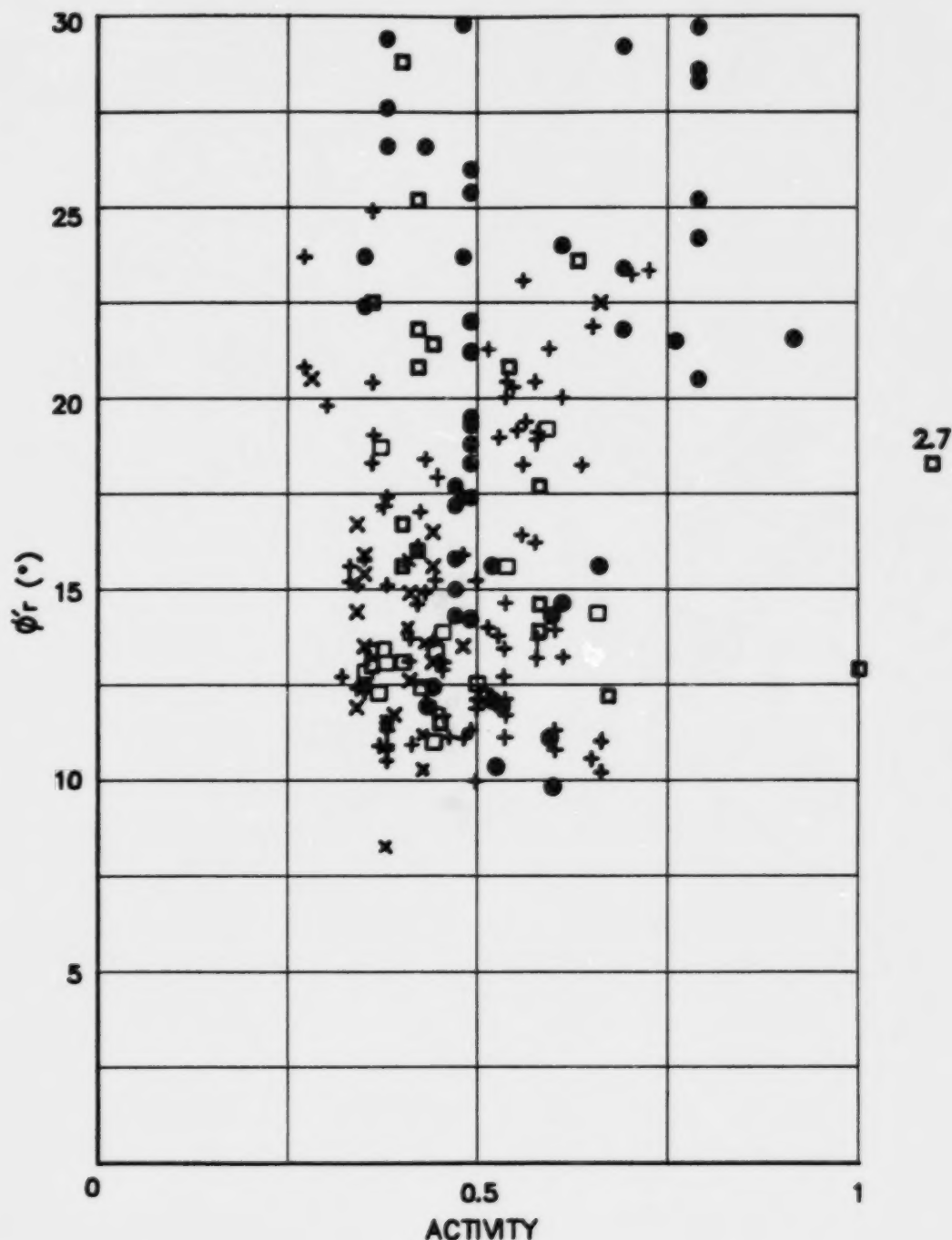
PLATE B-61



LEGEND:

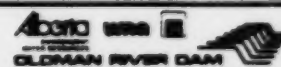
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- +
- SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- ×
- SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

  
ϕ_r VS ACTIVITY ELEVATION 1040m to 1050m
PLATE B-62



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
(SAMPLE MISALIGNED 31mm DURING TEST)



ϕ_r VS ACTIVITY
ALL COMBINED

PLATE B-64

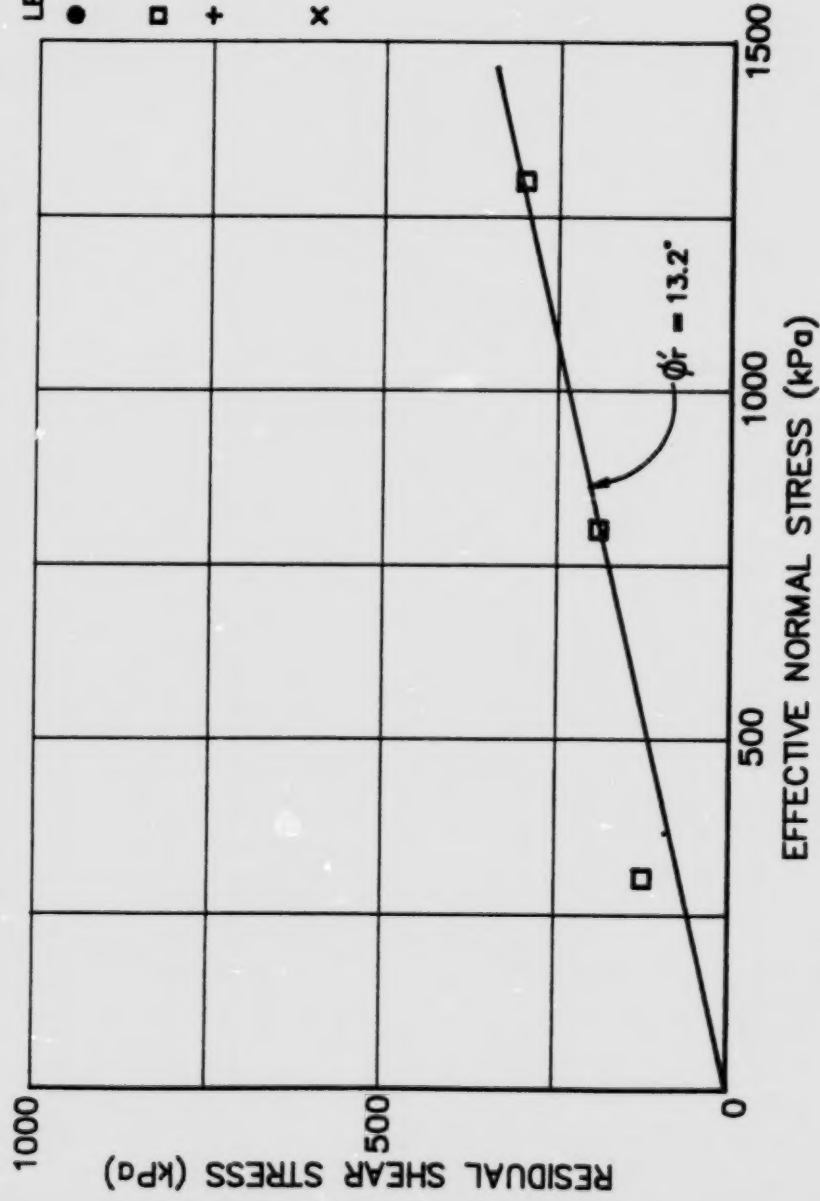
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = BC-86-D425R

SAMPLE NO. = 3

DEPTH = 27.27-27.30
27.24-27.27
27.20-27.23

ELEVATION = 1024.96-1024.93
1024.99-1024.96
1025.03-1025.00



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-65

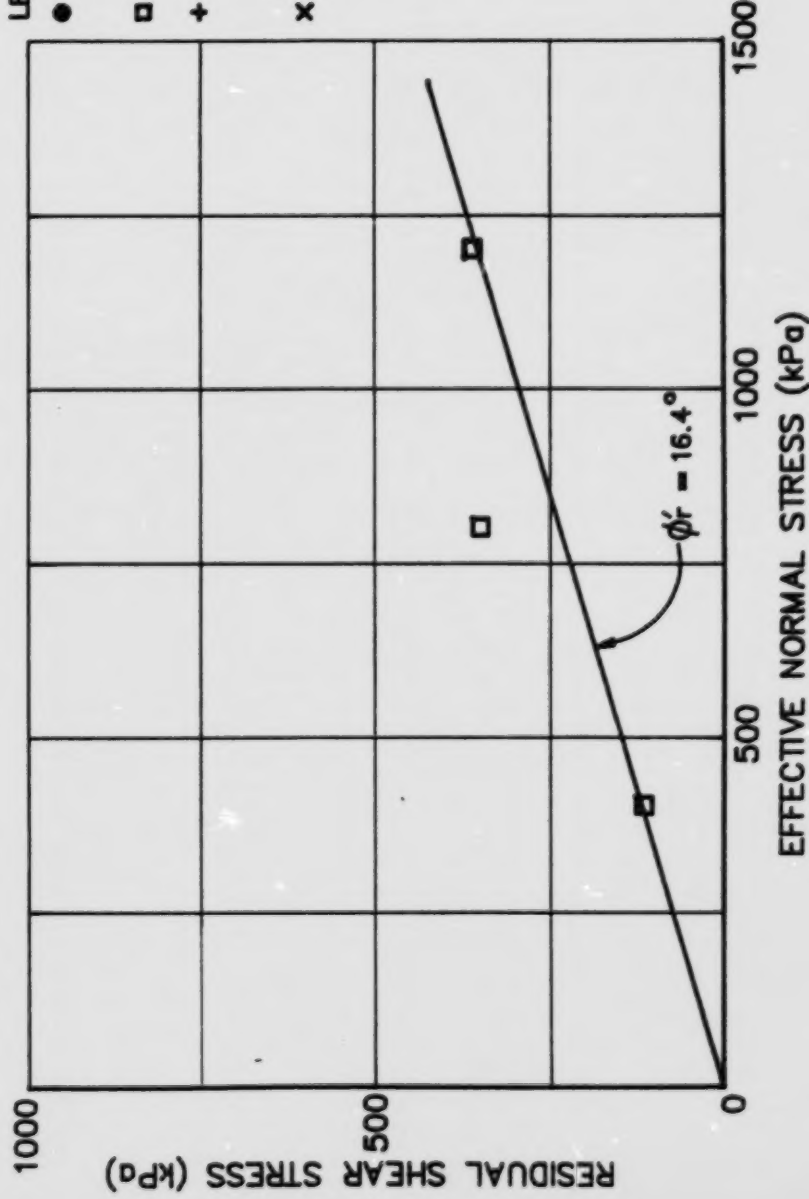
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = BC-86-D415

SAMPLE NO. = 9
10
12

DEPTH = 25.73
25.99
26.56

ELEVATION = 1031.73
1031.47
1030.90



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-66

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

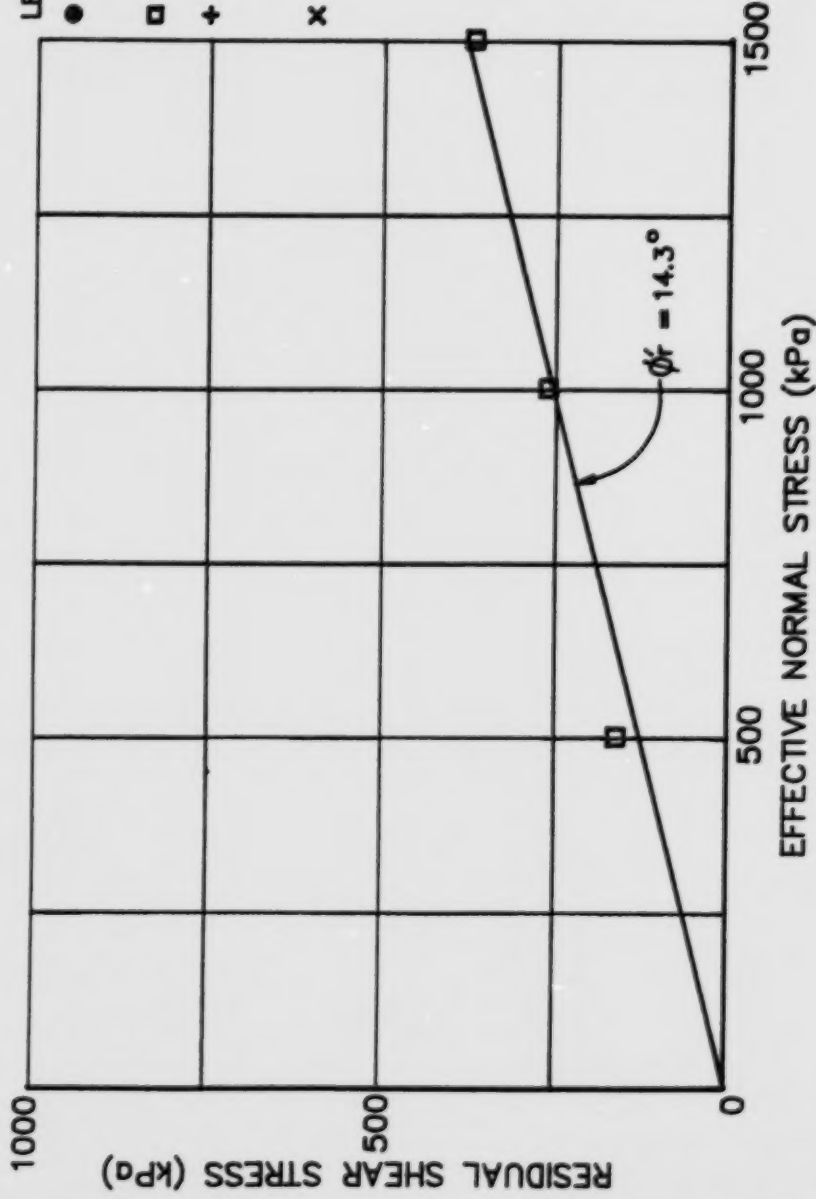
DRILL HOLE NO. = BC-85-D77R

SAMPLE NO. = 5

DEPTH = 26.46-26.83*

ELEVATION = 1025.20-1024.83*

* SAMPLE DEPTH



RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

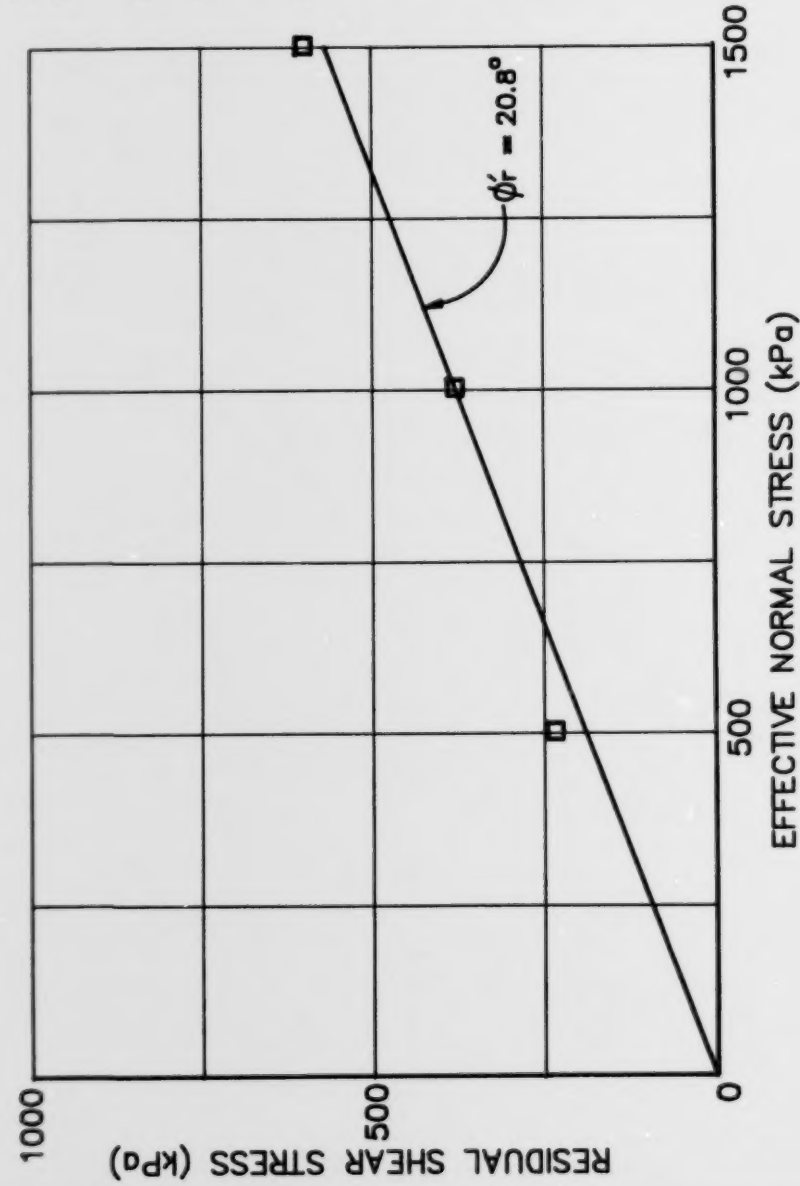
DRILL HOLE NO. = BC-85-D8

SAMPLE NO. = 9

DEPTH = 24.60-24.80*

ELEVATION = 1026.86-1026.66*

* SAMPLE DEPTH



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = BC-85-D10

SAMPLE NO. = 14

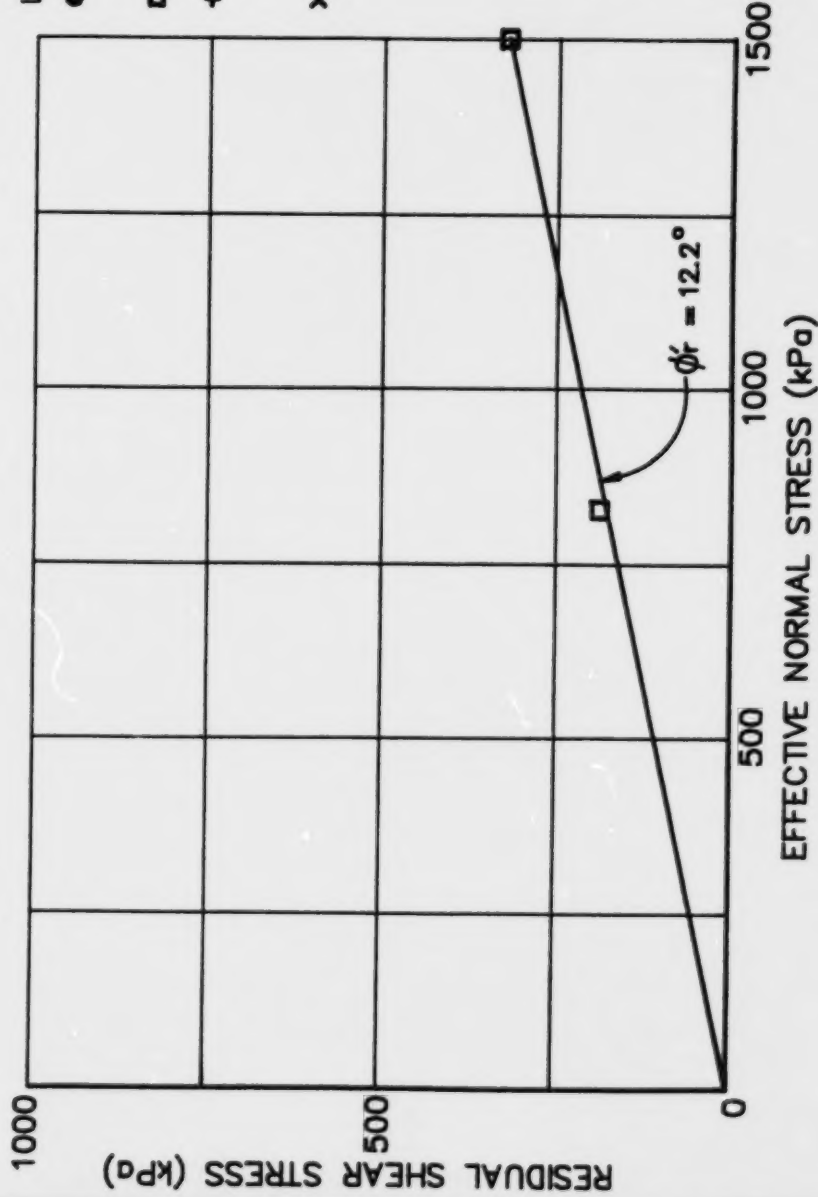
DEPTH = 69.95-70.10*

ELEVATION = 1003.45-1003.35*

* SAMPLE DEPTH

LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR FLOT

PLATE B-69

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

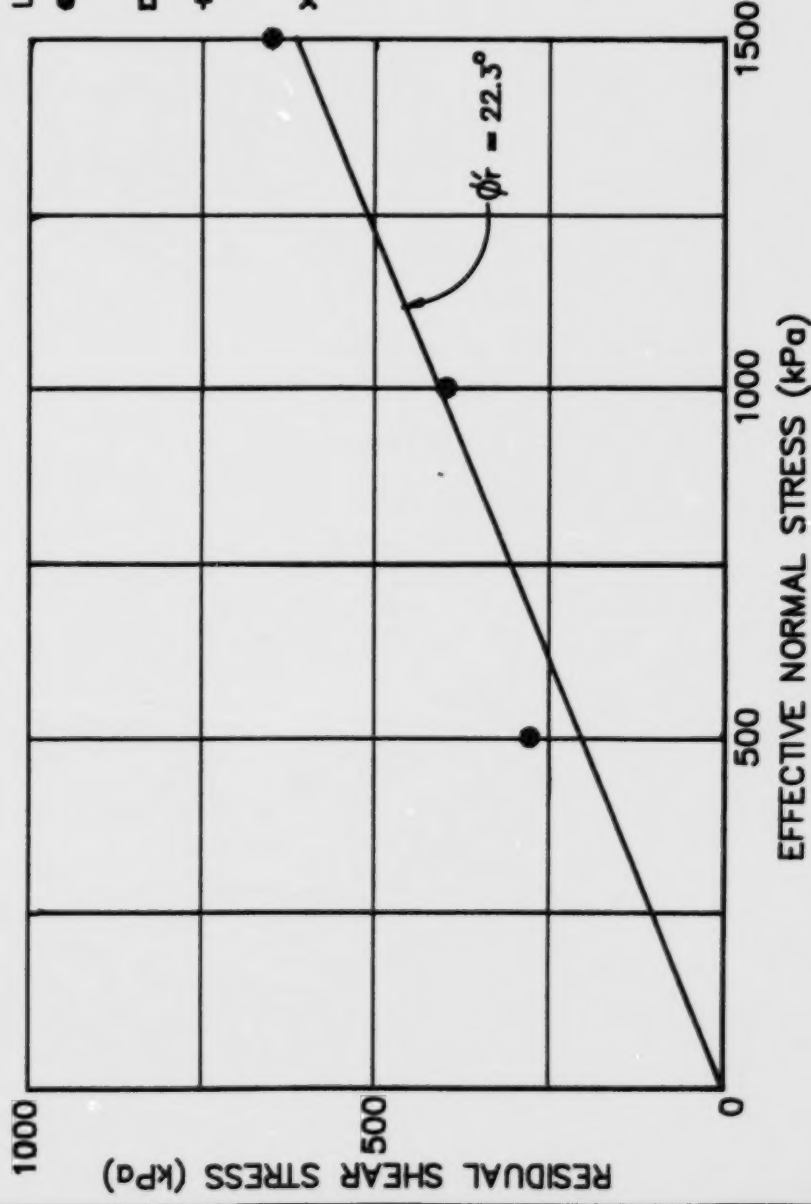
DRILL HOLE NO. = BC-85-G5

SAMPLE NO. = 6

DEPTH = 28.38-28.80*

ELEVATION = 1029.40-1028.98*

* SAMPLE DEPTH



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

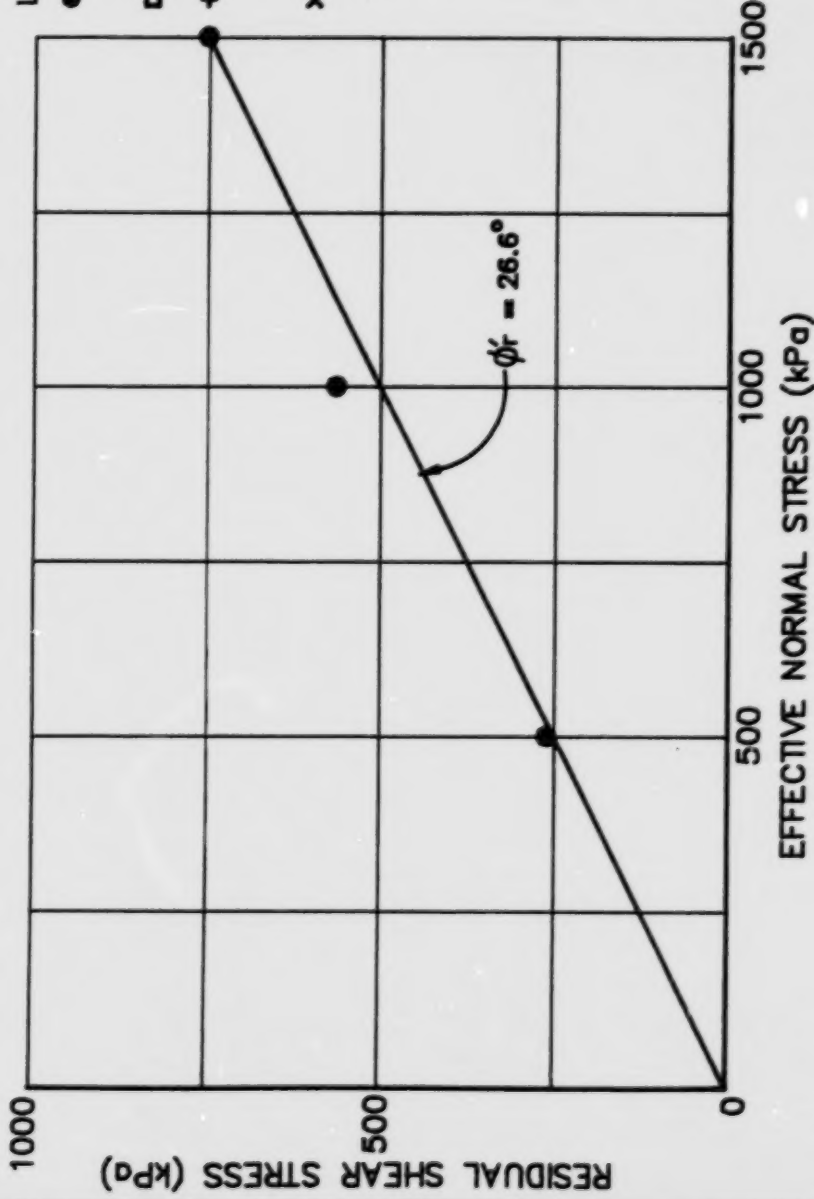
DRILL HOLE NO. = BC-85-G58

SAMPLE NO. = 7

DEPTH = 22.81-22.83*

ELEVATION = 1030.26-1030.24*

* SAMPLE DEPTH



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- × - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-71

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

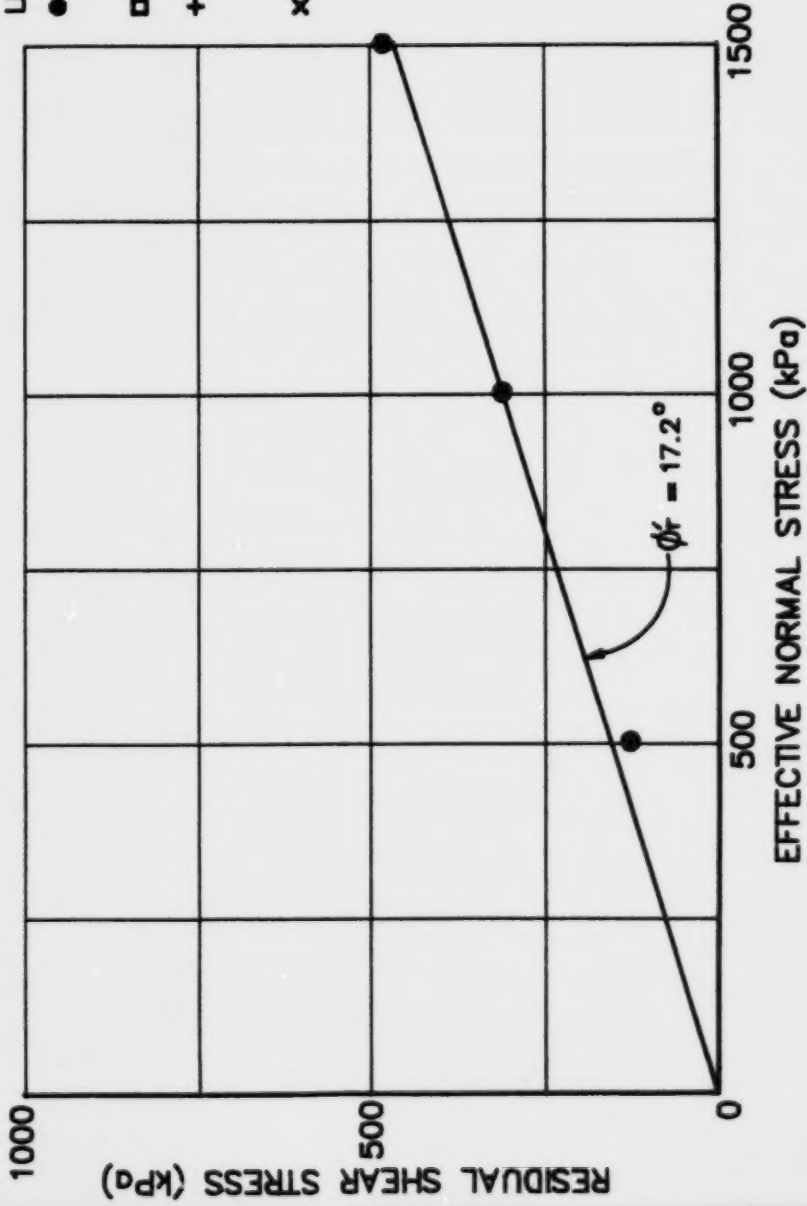
DRILL HOLE NO. = BC-85-D10

SAMPLE NO. = 10

DEPTH = 46.65
46.75
46.70

ELEVATION = 1019.97
1019.85
1019.88

- LEGEND:
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
 - - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
 - ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
 - × - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-72

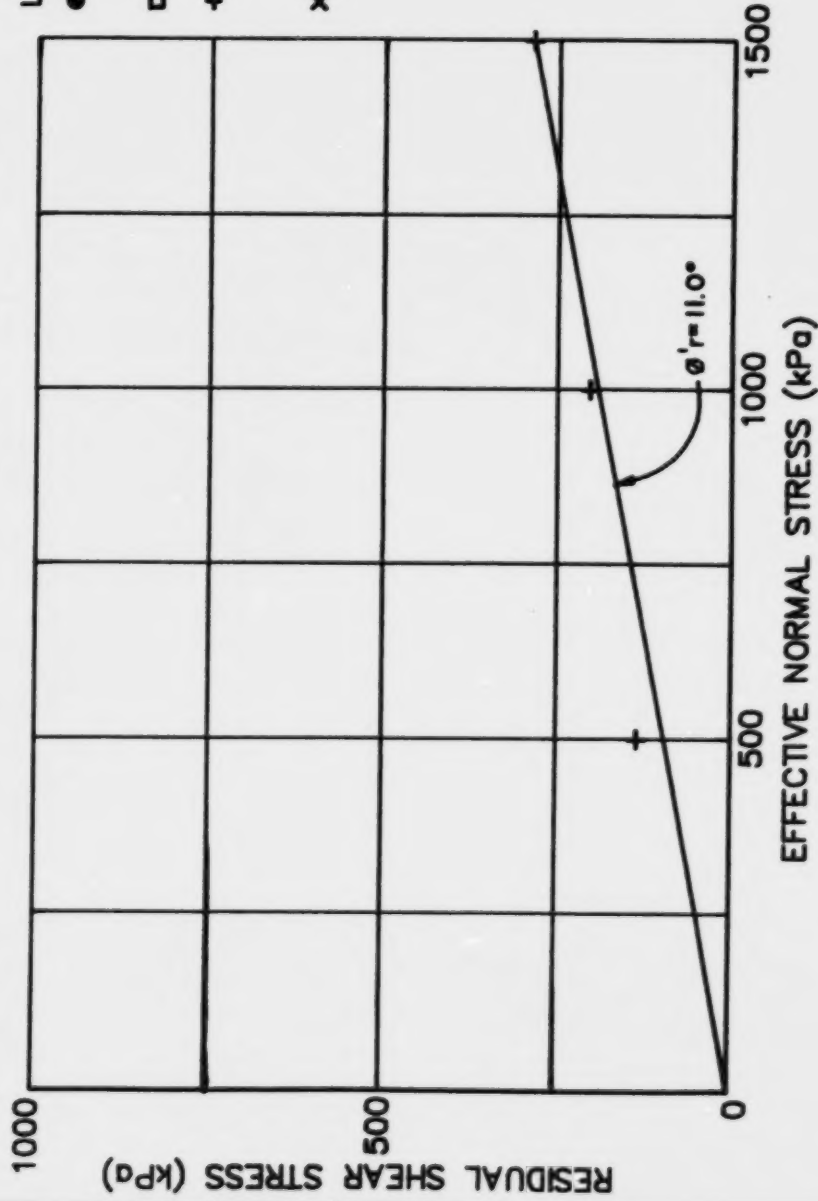
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-85-D95

SAMPLE NO. = 10A
10B
10C

DEPTH = 38.7
38.7
38.7

ELEVATION = 1031.25
1031.25
1031.25



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- +
- +
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

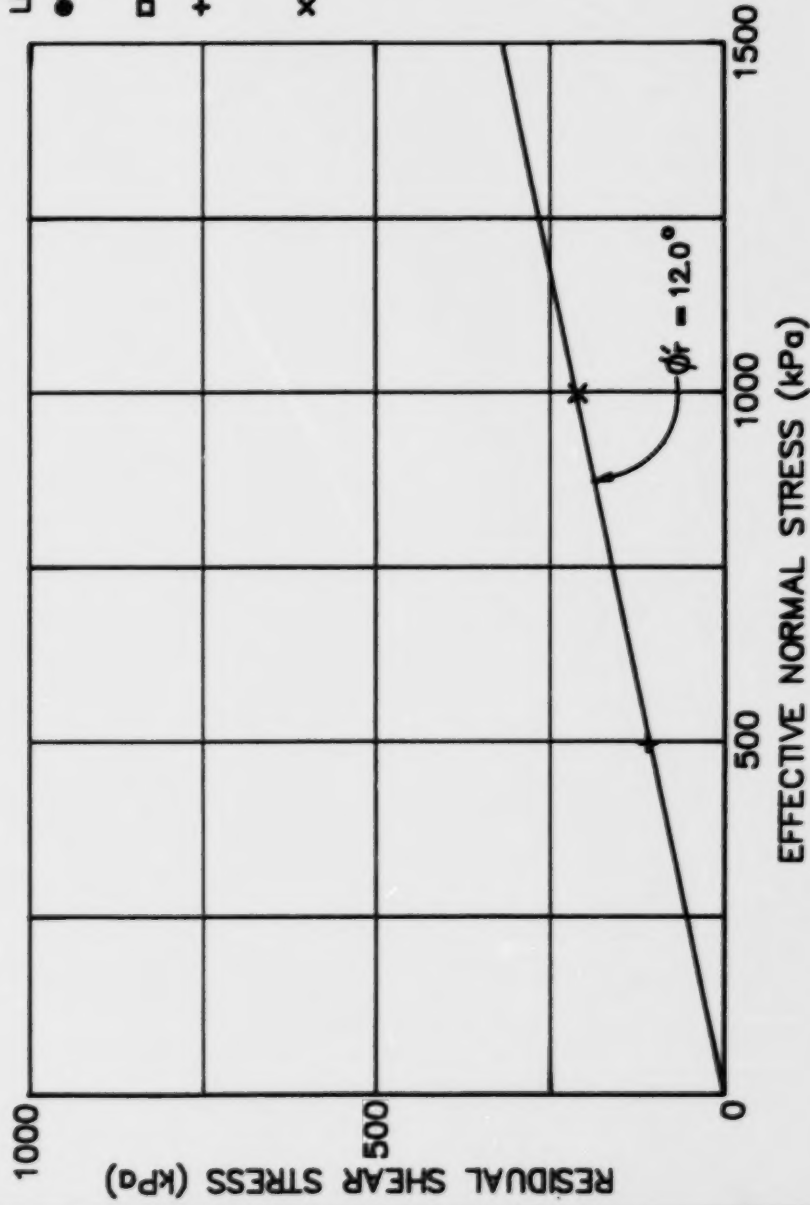
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-85-D95

SAMPLE NO. = 4C

DEPTH = 39.15

ELEVATION = 1030.80



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- +

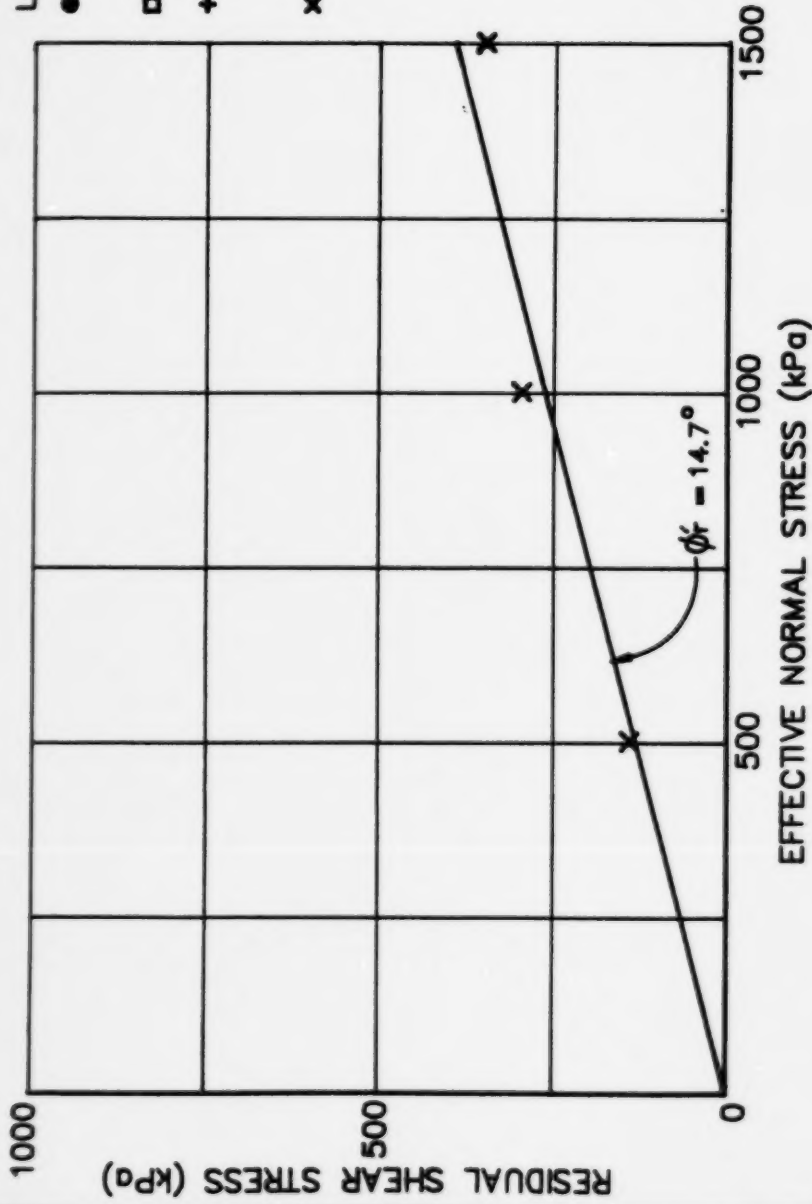
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-85-D95

SAMPLE NO. = 11B

DEPTH = 44.36

ELEVATION = 1025.59



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-75

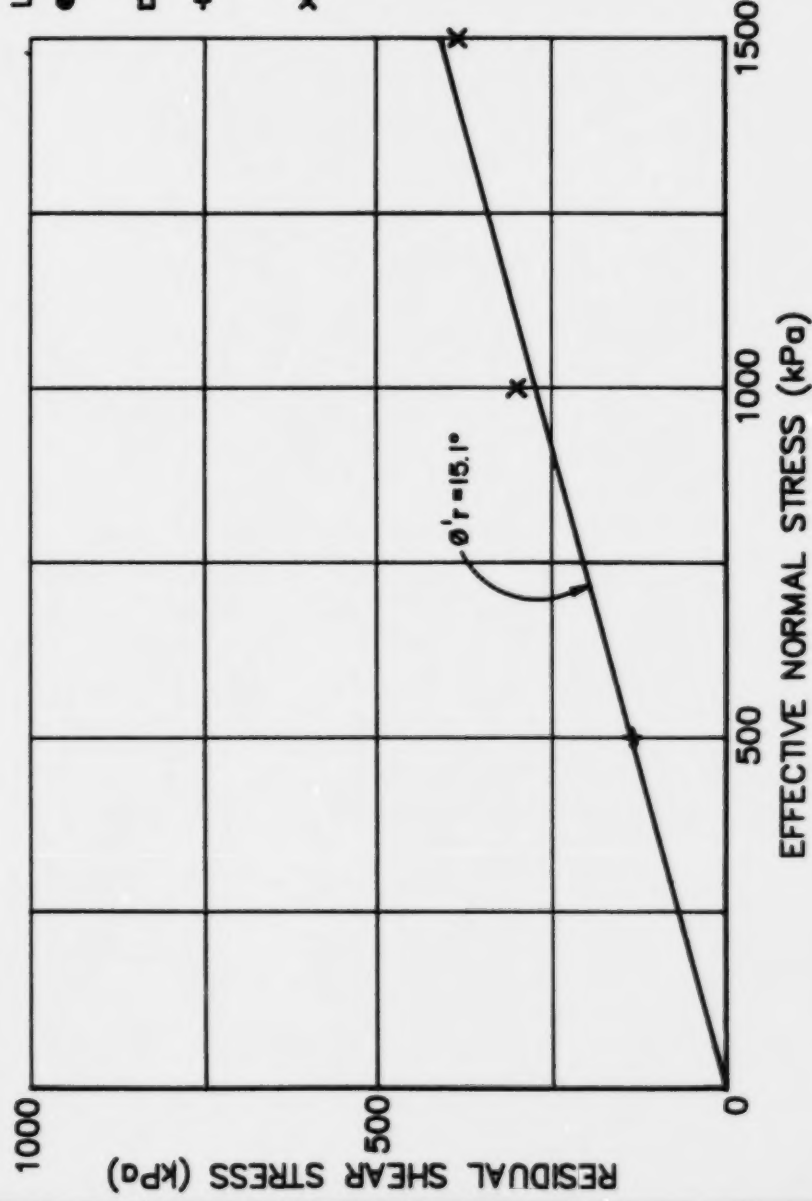
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-85-D95

SAMPLE NO. = 8D
8C

DEPTH = 42.05
42.05

ELEVATION = 1027.9
1027.9



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- ×
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-76

RESIDUAL SHEAR STRENGTH

(INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

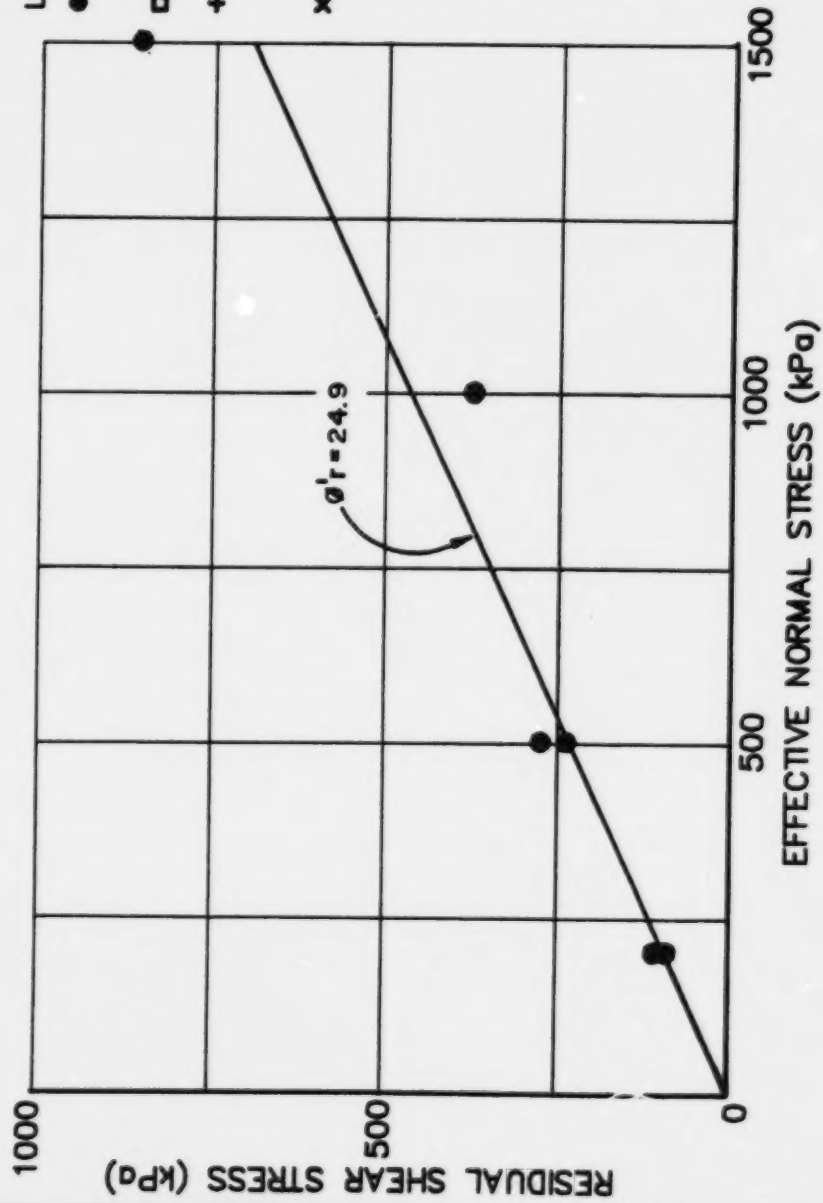
DRILL HOLE NO. = BC-85-G58

SAMPLE NO. = 1

DEPTH = 6.26-6.51*

ELEVATION = 1046.81-1046.56#

• SAMPLE DEPTH



LEGEND:

- | | | |
|---|---|--|
| ● | - | INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING |
| | - | 5 cm x 5 cm DIRECT SHEAR TEST |
| □ | - | SEAM SAMPLE OBTAINED FROM DRILLHOLE |
| | - | 5 cm x 5 cm DIRECT SHEAR TEST |
| + | - | SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST) |
| x | - | SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST) |

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = BC-85-G58

SAMPLE NO. = 2

DEPTH = 9.0-9.41*

ELEVATION = 1044.07-1043.66*

* SAMPLE DEPTH



RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

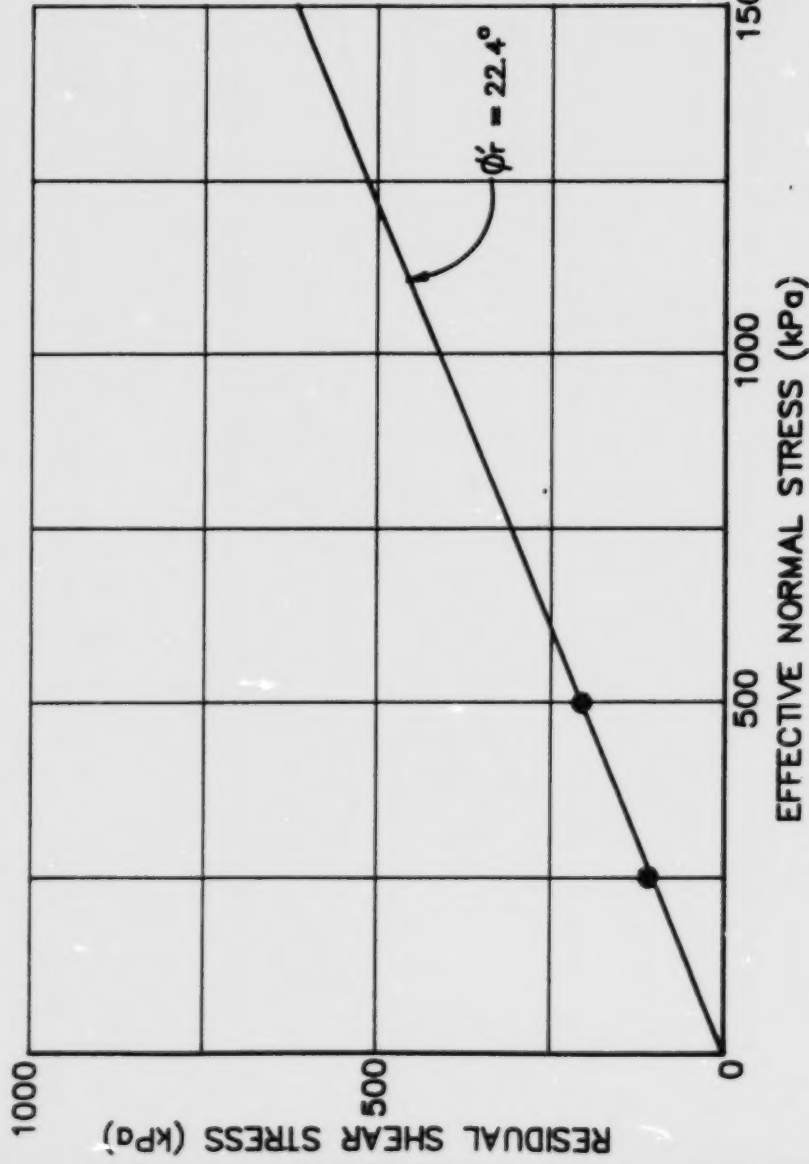
DRILL HOLE NO. = BC-85-D12

SAMPLE NO. = 2

DEPTH = 13.30-13.56*

ELEVATION = 1041.0-1040.74

* SAMPLE DEPTH



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-79

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = BC-85-D12

SAMPLE NO. = 3

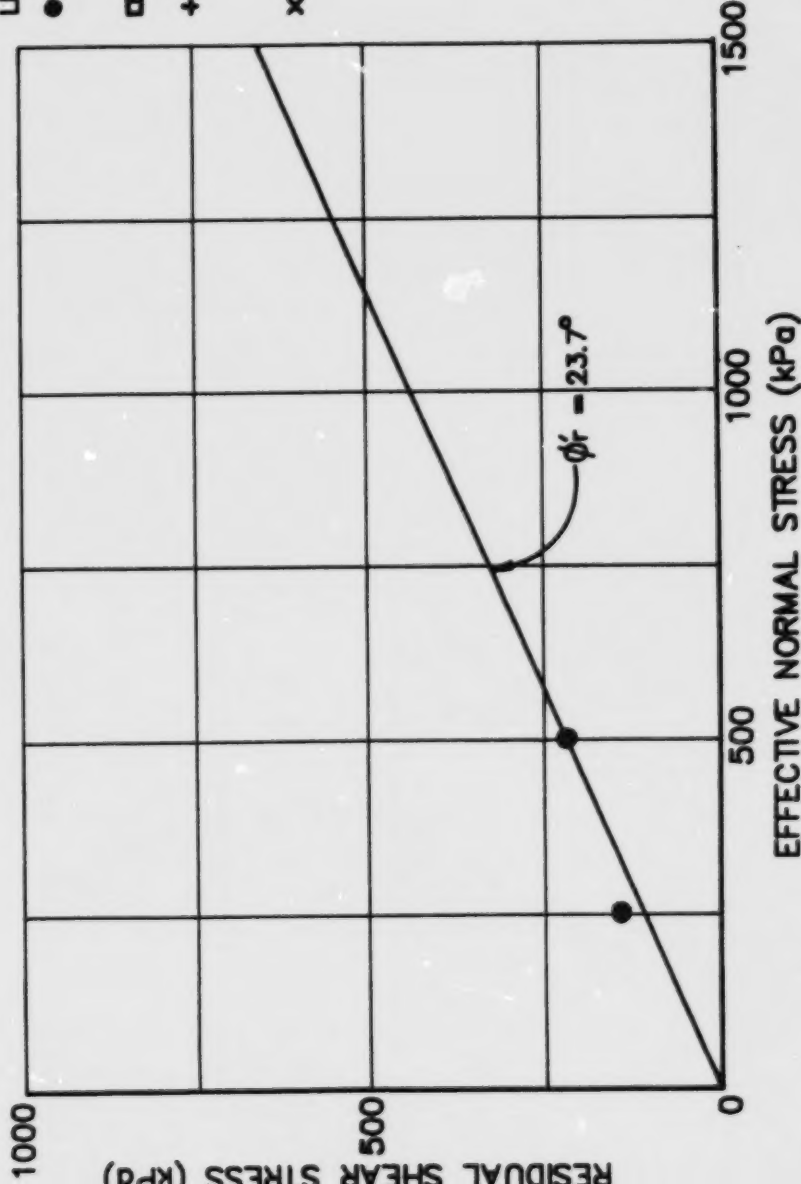
DEPTH = 14.90-15.20*

ELEVATION = 1039.4-1039.0*

* SAMPLE DEPTH

LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

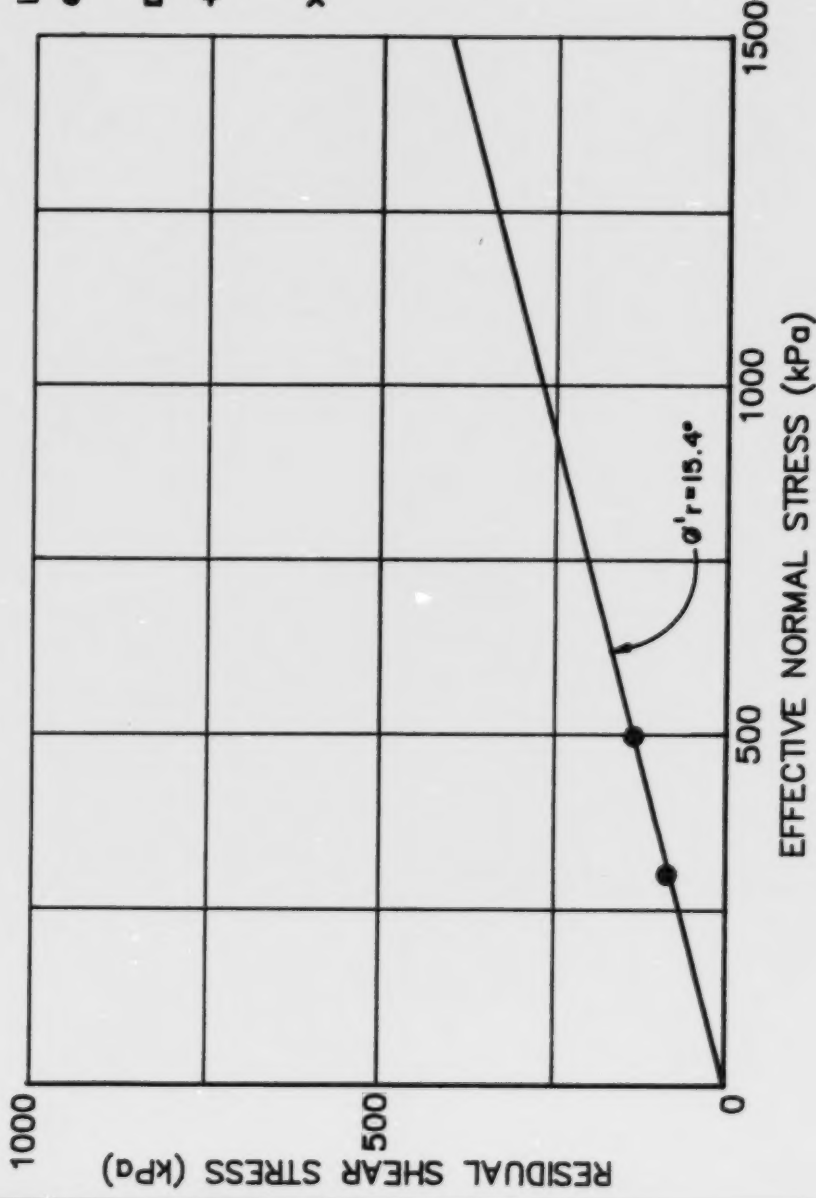
DRILL HOLE NO. = BC-85-D84

SAMPLE NO. = 4

DEPTH = 7.93-8.37*

ELEVATION = 1045.36-1044.92*

* SAMPLE DEPTH



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR FLOT

PLATE B-8I

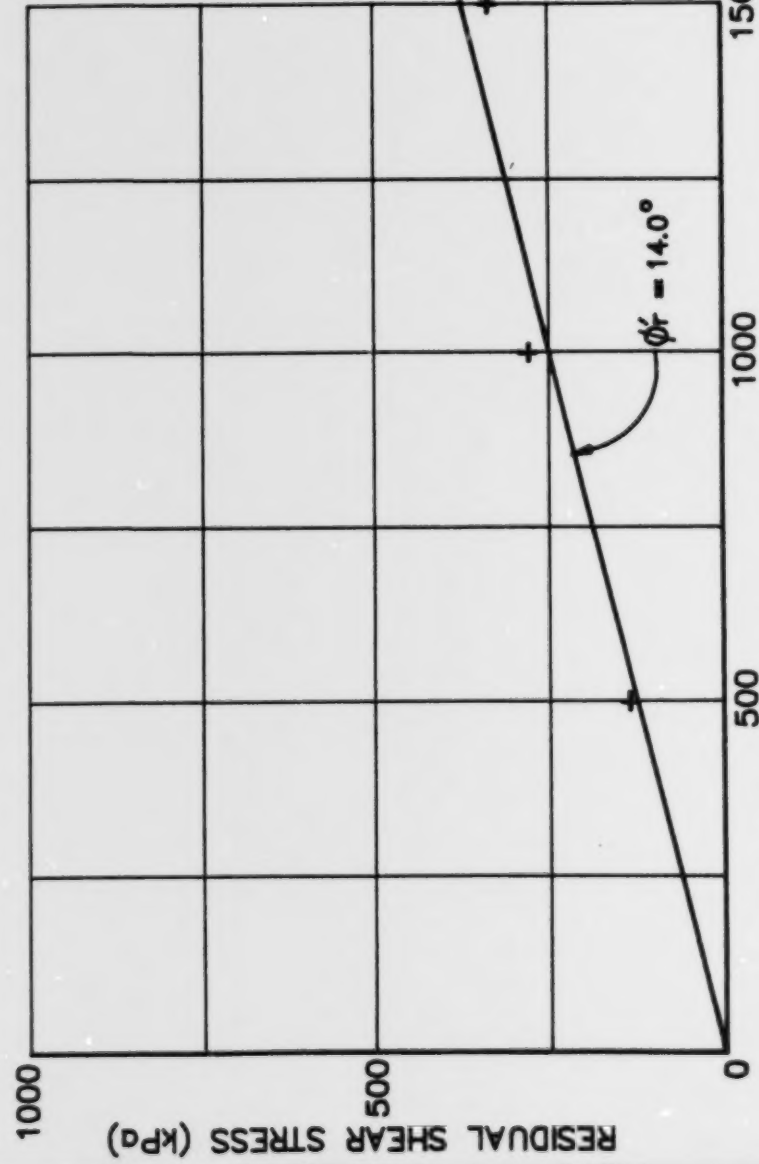
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-85-D95

SAMPLE NO. = 1A & 1B

DEPTH = 20.53
20.53
20.53

ELEVATION = 1049.4
1049.4
1049.4



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
-
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-82

RESIDUAL SHEAR STRENGTH

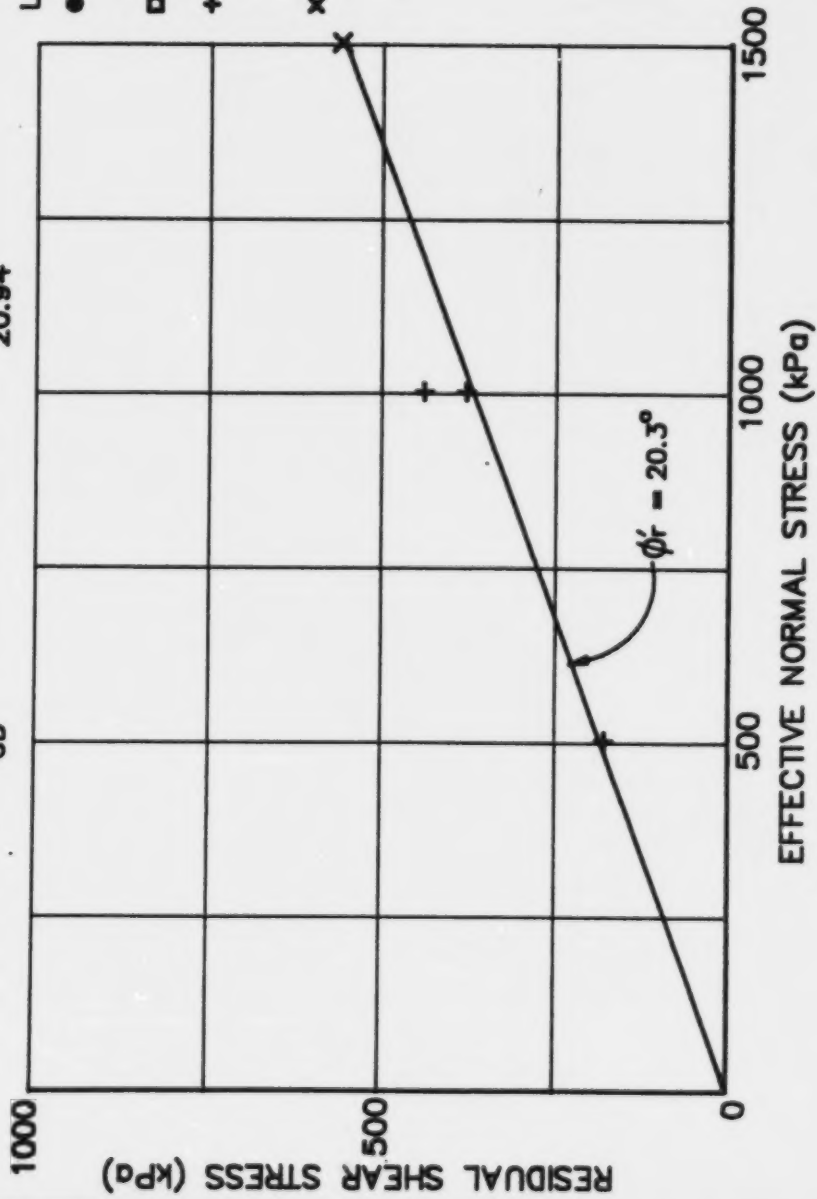
(INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-85-D95

SAMPLE NO. = 6A
6B
6C
6D

DEPTH = 20.88
20.88
20.88
20.94

ELEVATION = 1049.07
1049.07
1049.07
1049.01



LEGEND:

- ● INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- □ 5 cm x 5 cm DIRECT SHEAR TEST
- □ SEAM SAMPLE OBTAINED FROM DRILLHOLE
- + 5 cm x 5 cm DIRECT SHEAR TEST
- + SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- X SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

RESIDUAL SHEAR
STRENGTH-MOHR PLOT

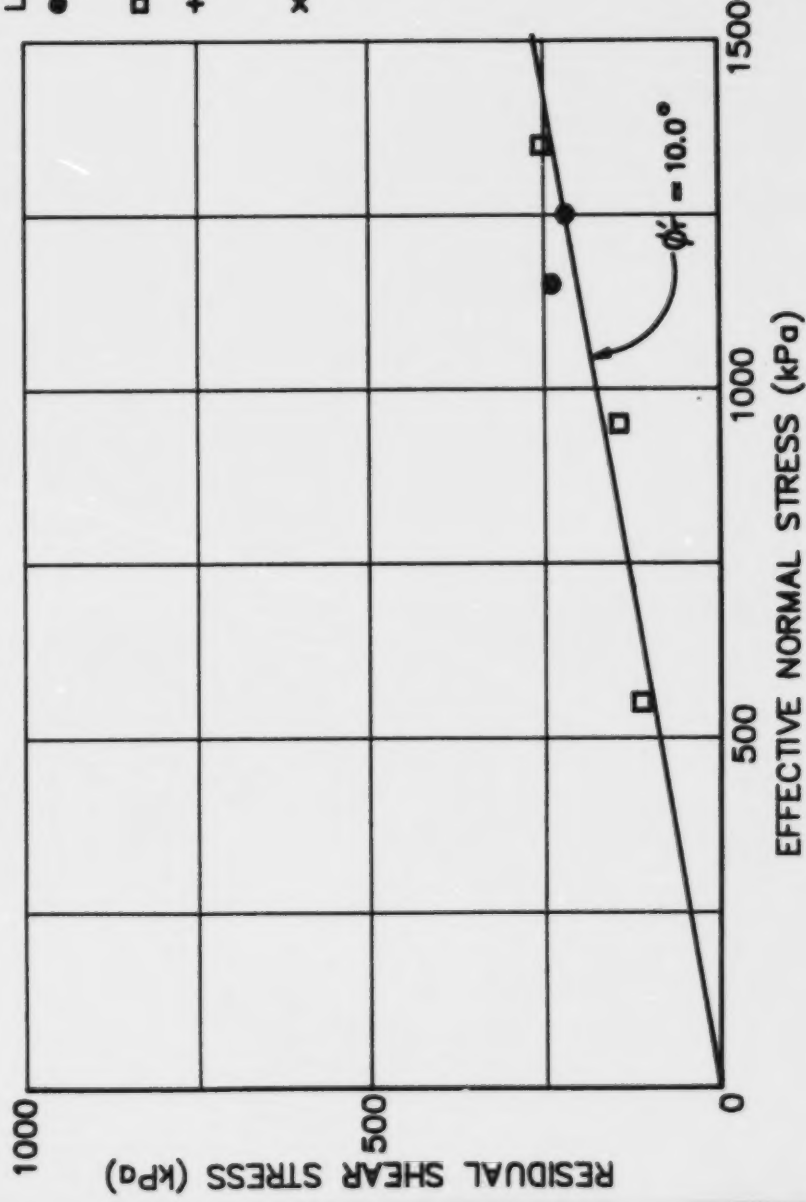
PLATE B-83

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. =	SAMPLE NO. =	DEPTH =	ELEVATION =
CH-87-S758	10	52.33	1066.6
CH-87-S759	15	41.20	1068.74
CH-87-S750	13	67.80	1069.49
CH-87-S751	7	69.77	1067.55
CH-87-S754	19	63.87	1067.94

LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

RESIDUAL SHEAR STRENGTH

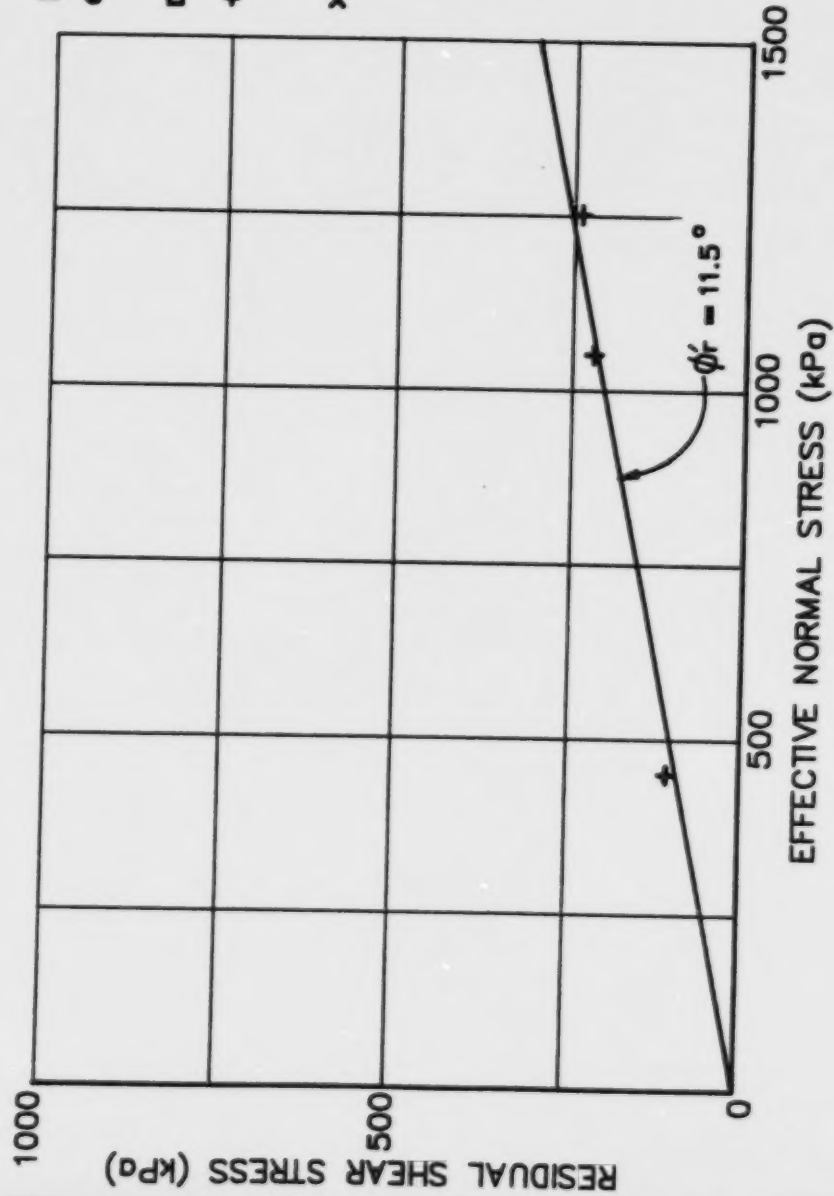
(INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = EAST ABUTMENT

SAMPLE NO. = 1

DEPTH =

ELEVATION = 1065.69



LEGEND:

- | | | |
|---|---|---|
| ● | - | INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST |
| □ | - | SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST |
| + | - | SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH 10 cm x 10 cm DIRECT SHEAR
TEST (SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST) |
| x | - | SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH 10 cm x 10 cm DIRECT SHEAR
TEST (SAMPLE MISALIGNED ≥ 1 mm
DURING TEST) |

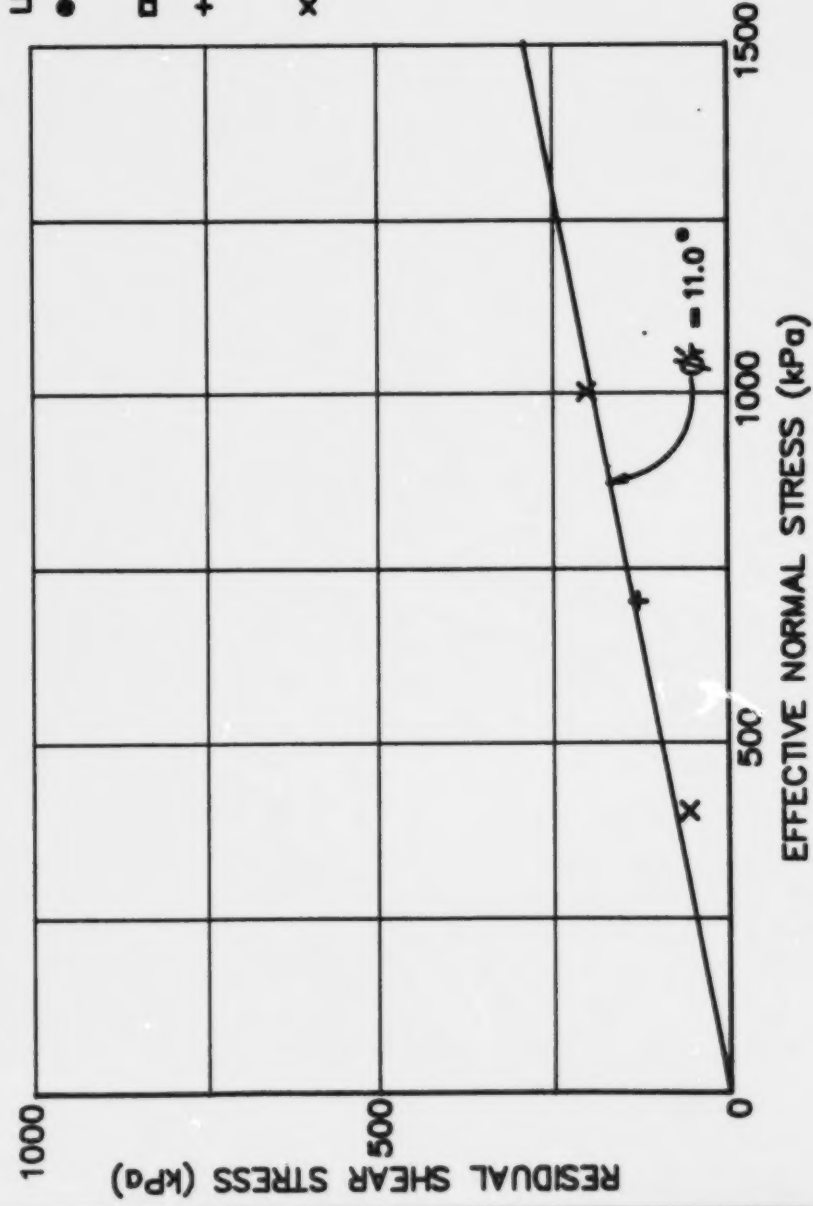
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 38

DEPTH = 47.41

ELEVATION = 1087.97



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-86

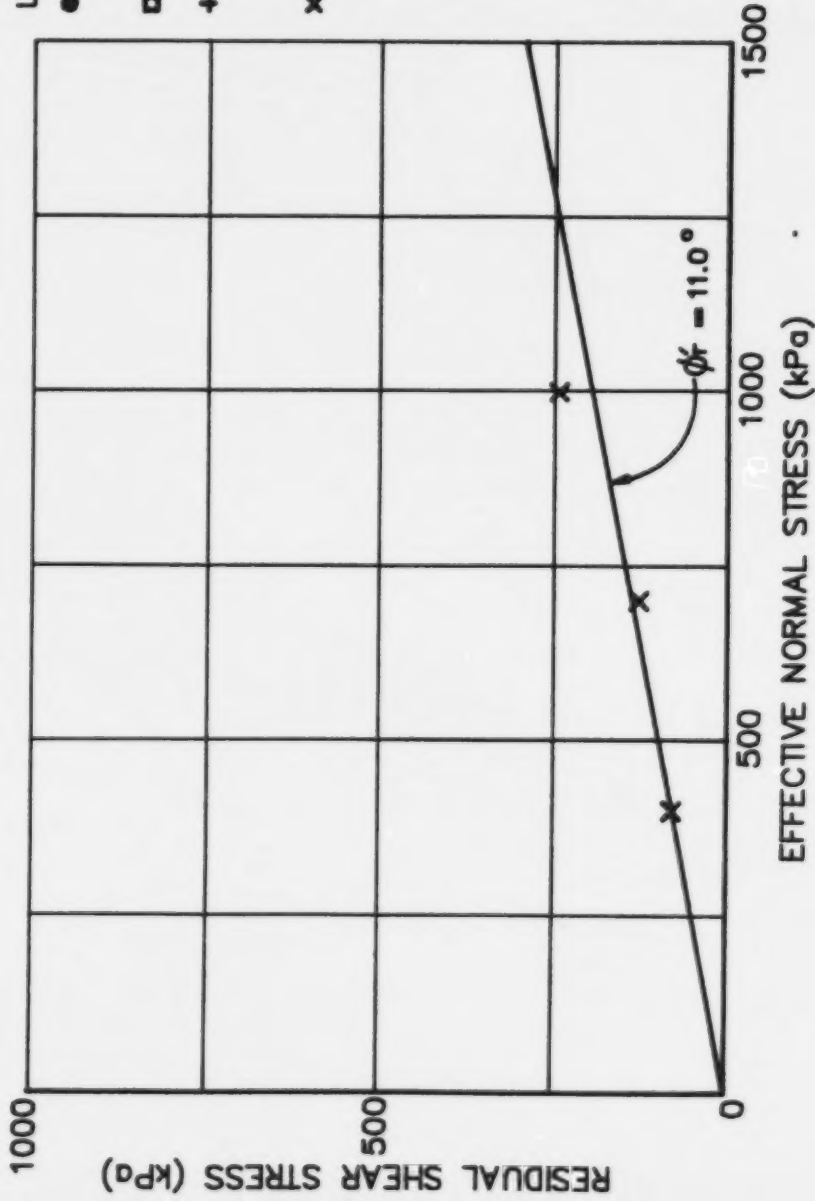
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 3C

DEPTH = 47.61

ELEVATION = 1087.77



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)

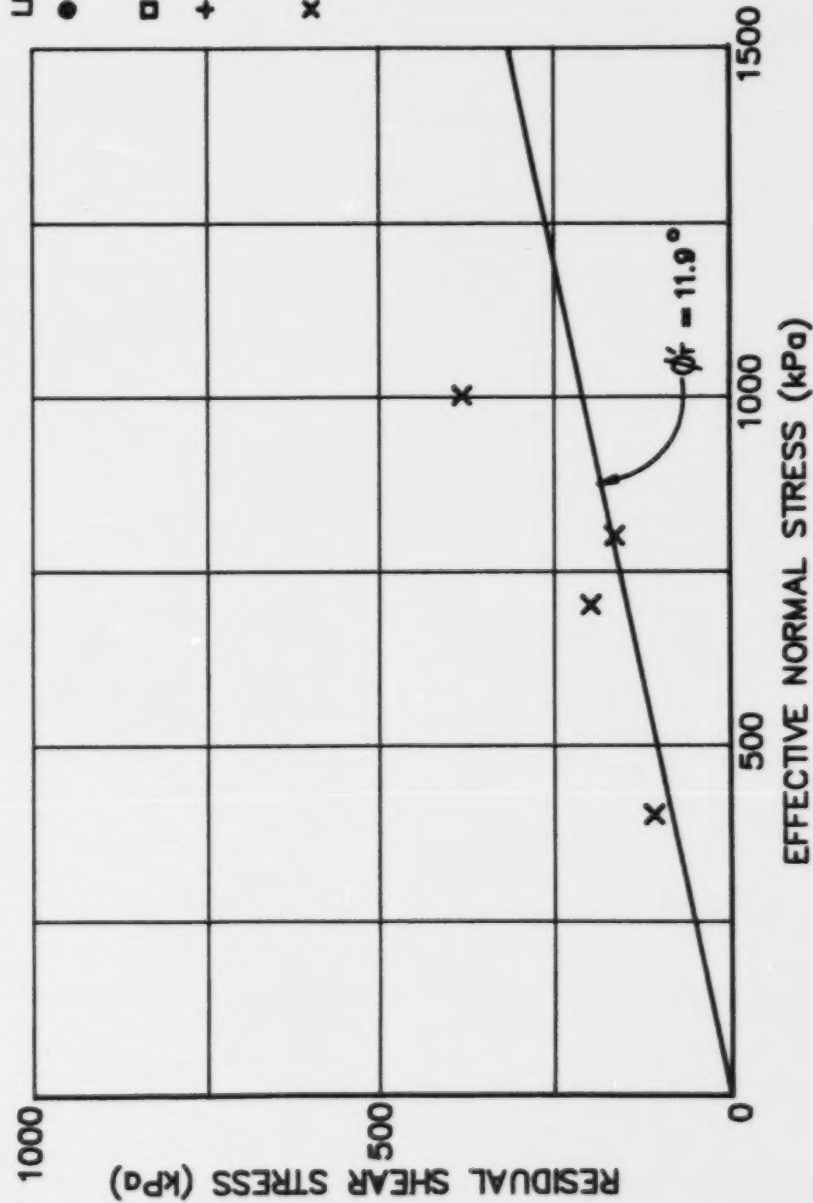
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 28

DEPTH = 48.34

ELEVATION = 1087.04



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MESASURED 2.1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-88

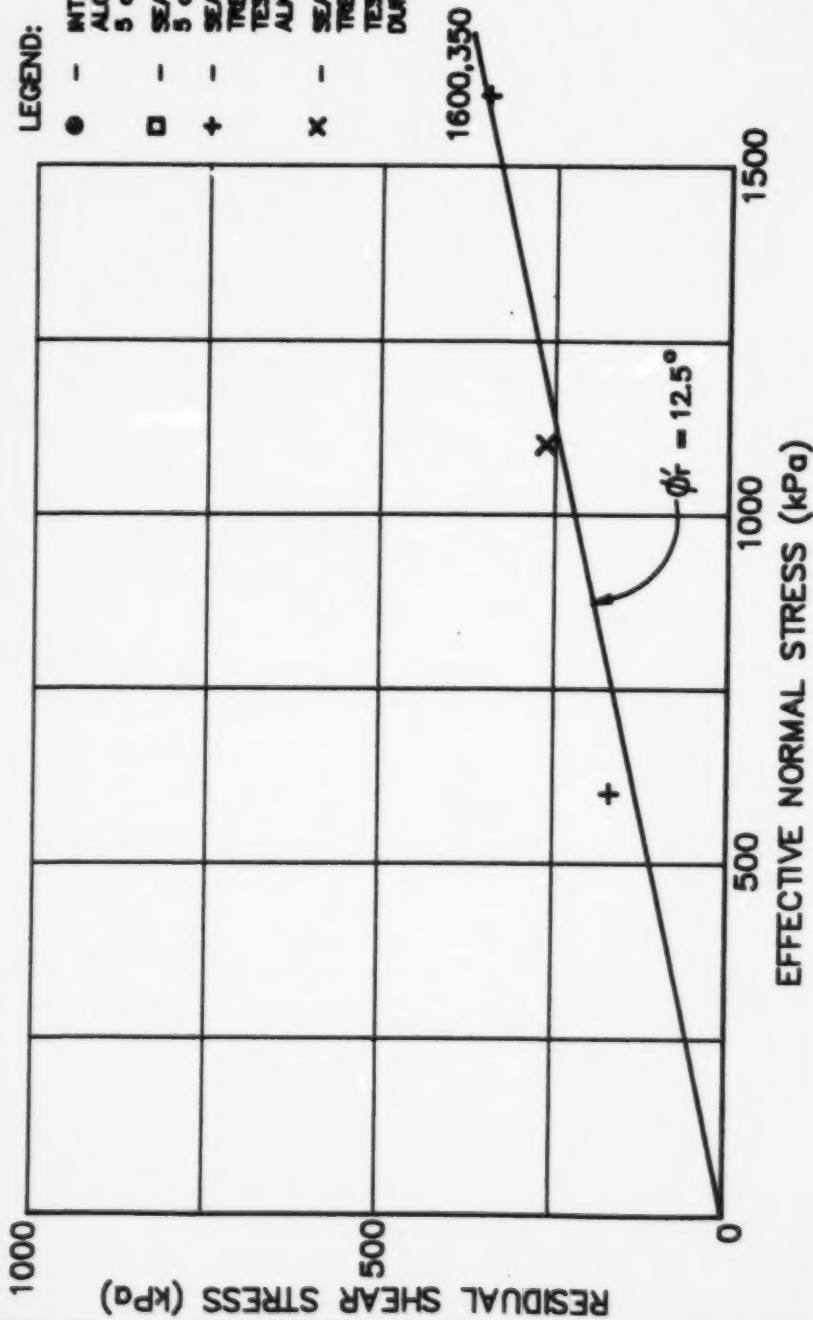
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 1B

DEPTH = 50.55

ELEVATION = 1084.83



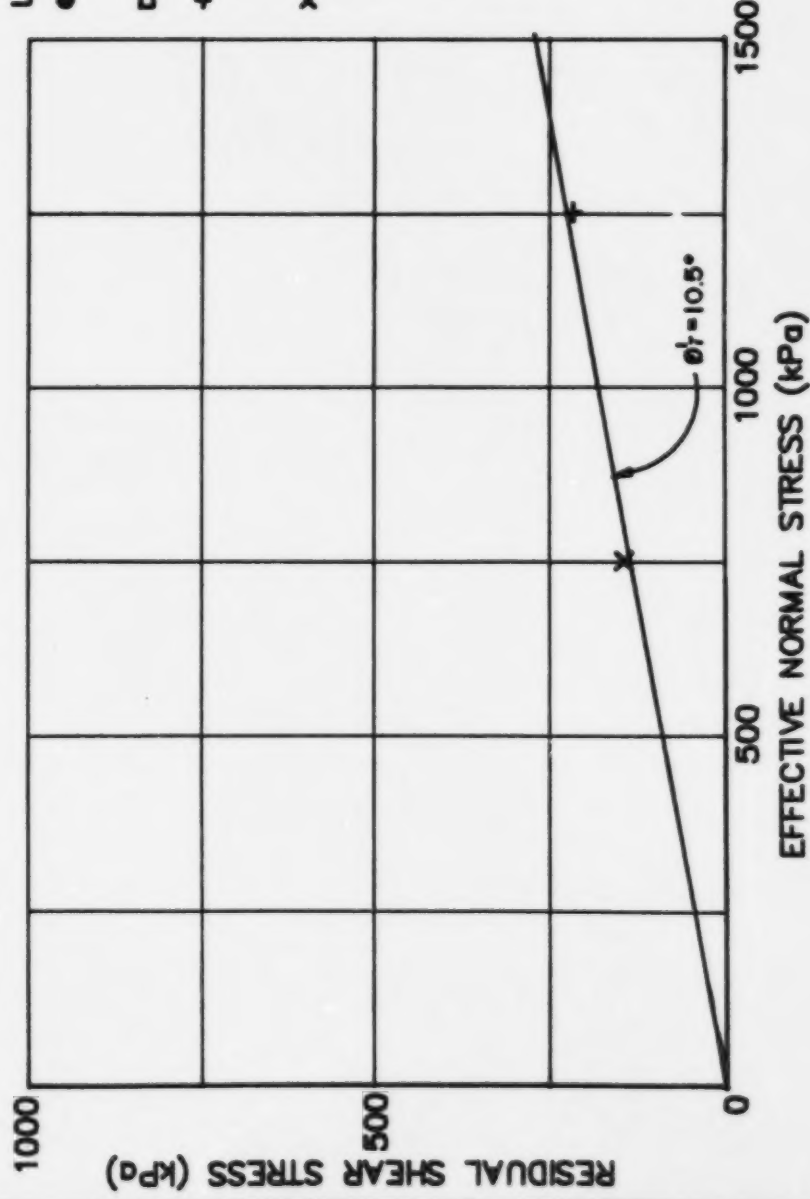
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = DT-87-B8III

SAMPLE NO. = 3

DEPTH =

ELEVATION = 1089.04.



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MESALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-90

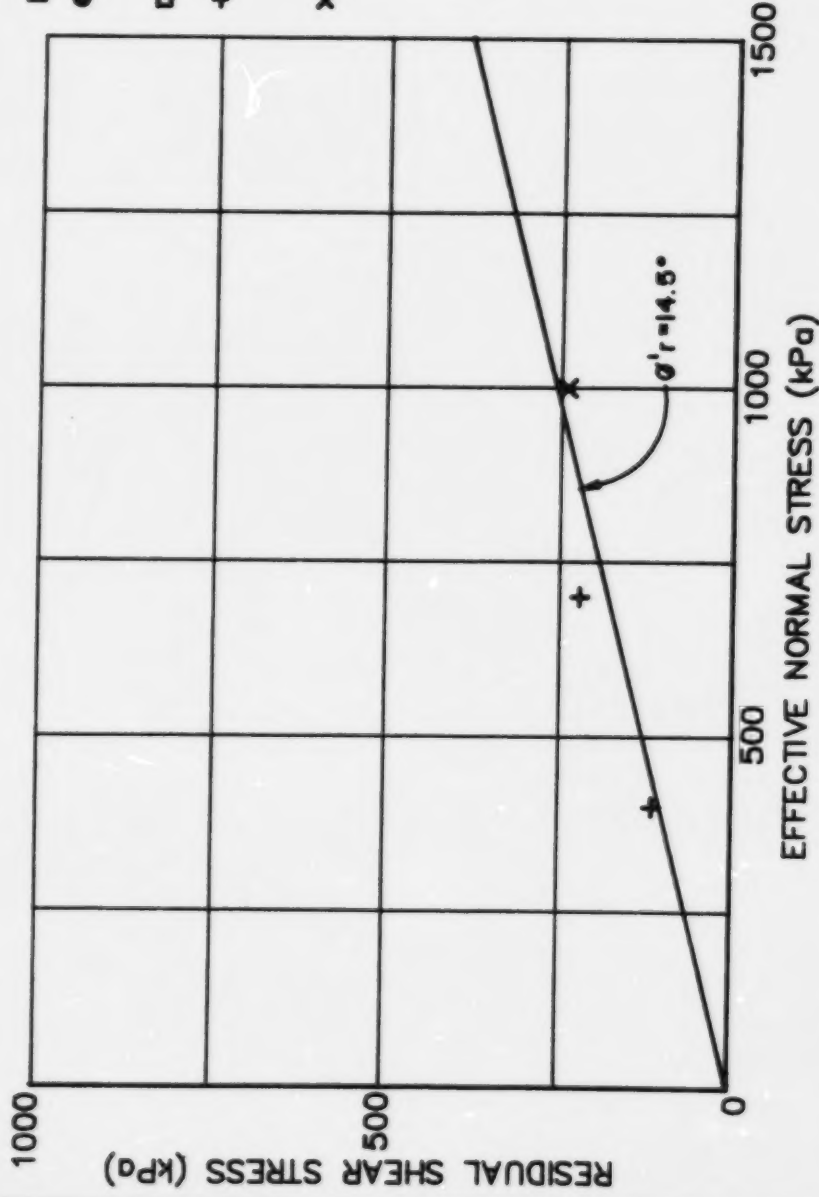
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 4B

DEPTH = 41.32

ELEVATION = 1094.06



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- +



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-91

ELEVATION = 1100.18
1100.12



- | | | |
|---|---|--|
| ● | - | INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING |
| | - | 5 cm x 5 cm DIRECT SHEAR TEST |
| □ | - | SEAM SAMPLE OBTAINED FROM DRILLHOLE |
| | - | 5 cm x 5 cm DIRECT SHEAR TEST |
| + | - | SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST) |
| x | - | SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MICALIGNED ≥ 1 mm DURING TEST) |

RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

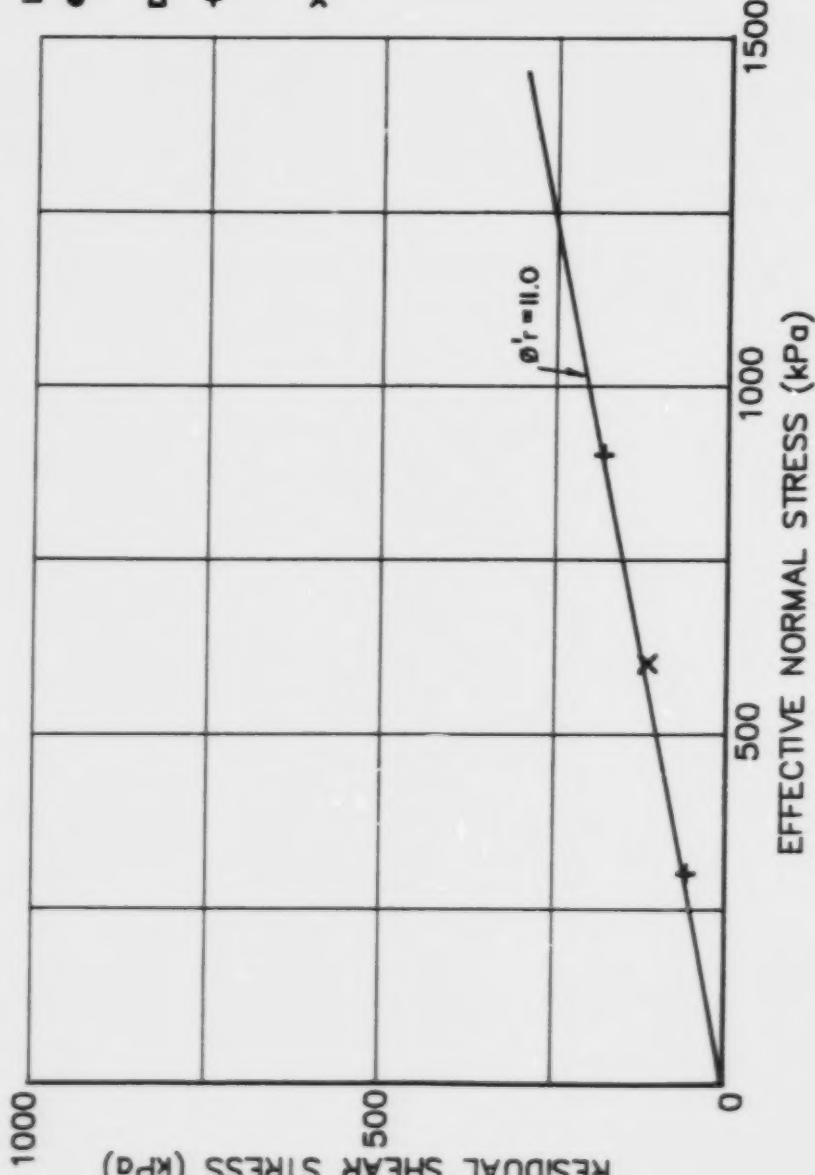
SAMPLE NO. = 6B

DEPTH = 30.63

ELEVATION = 1104.75

LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- ✕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



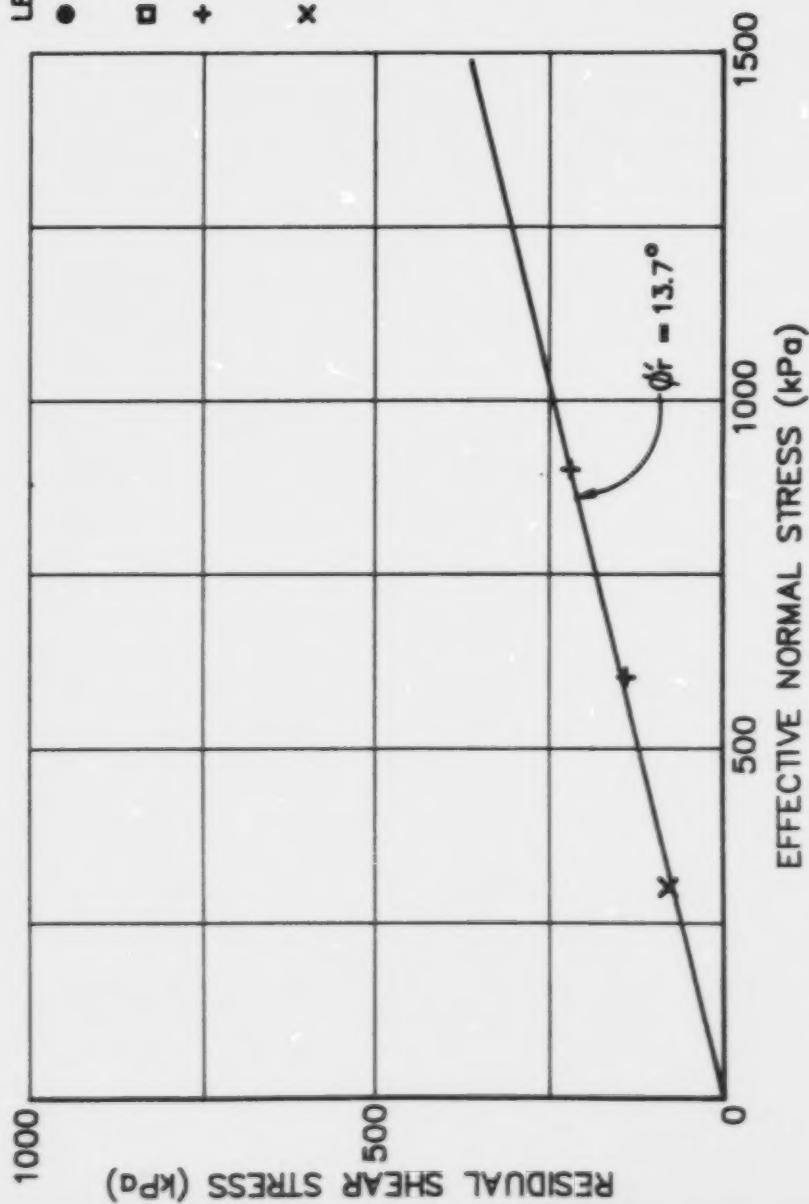
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 6D

DEPTH = 30.63

ELEVATION = 1104.75



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
 - - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
 - +
 - x
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-94

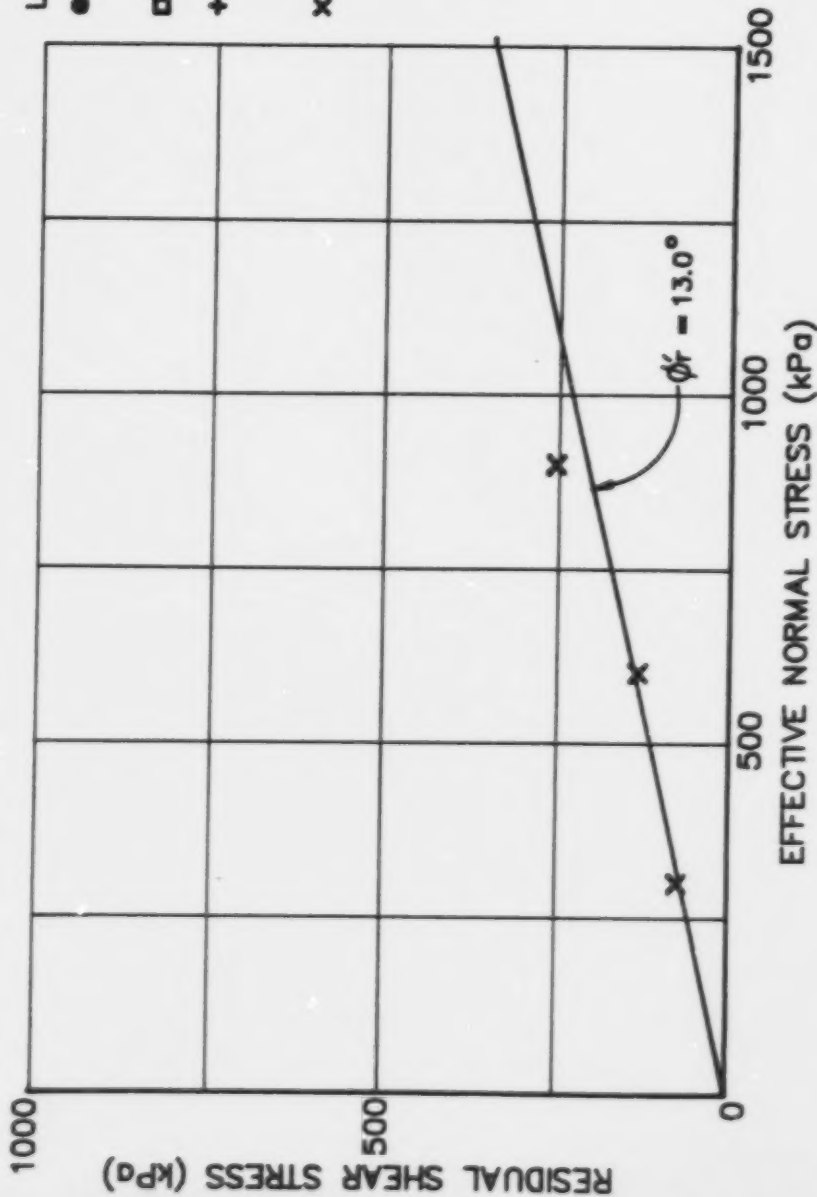
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 7B

DEPTH = 30.70

ELEVATION = 1104.68



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-95

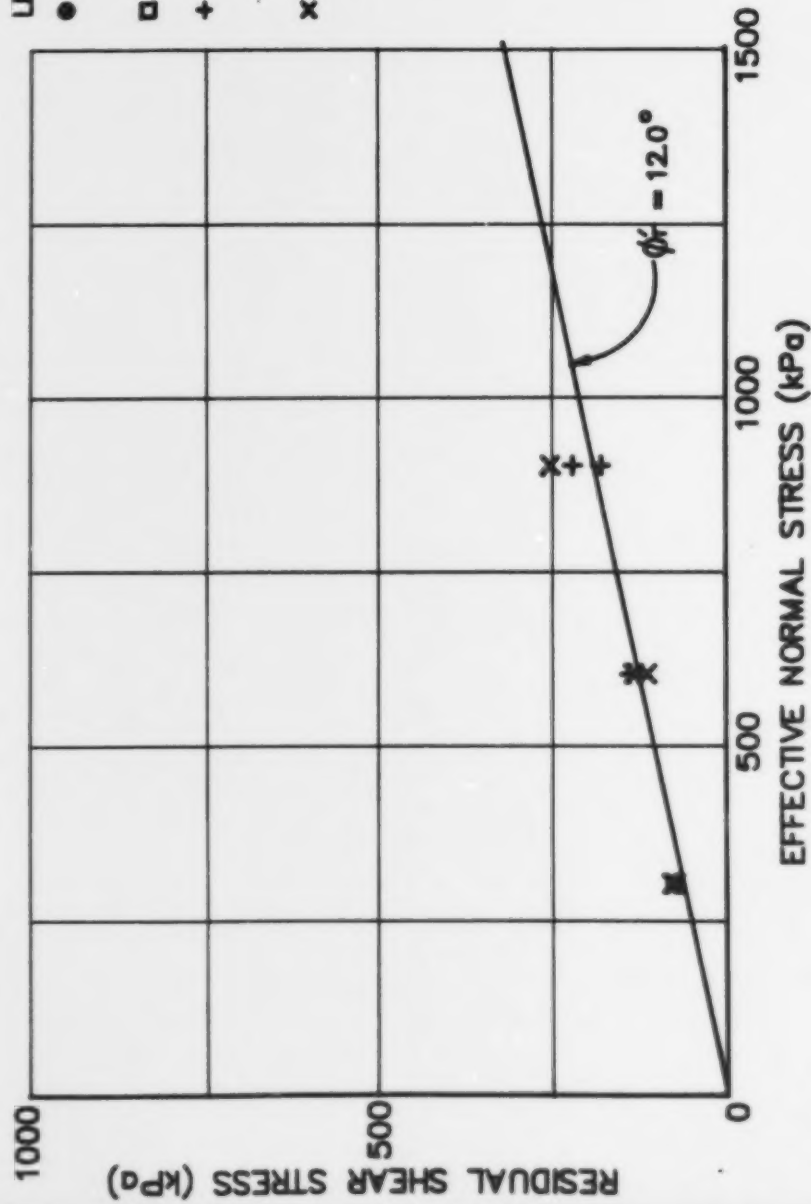
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 6B,6D,7B

DEPTH = 30.63
30.70

ELEVATION = 1104.75
1104.68



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE REMAINED IN LATERAL ALIGNMENT DURING TEST)
- x - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH 10 cm x 10 cm DIRECT SHEAR TEST (SAMPLE MISALIGNED ≥ 1 mm DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-96

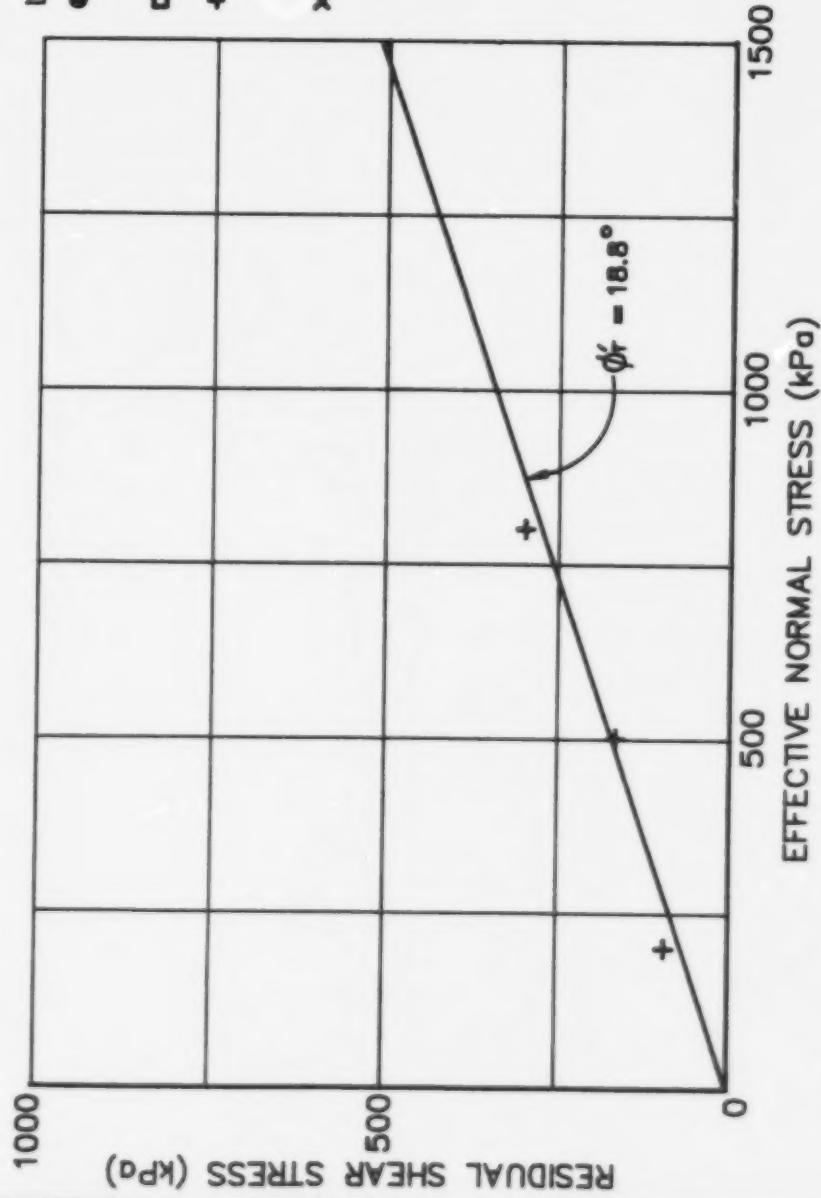
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 88

DEPTH = 29.75

ELEVATION = 1105.63



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- +

SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST

SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH 10 cm x 10 cm DIRECT SHEAR
TEST (SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)

SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH 10 cm x 10 cm DIRECT SHEAR
TEST (SAMPLE MISALIGNED ≥ 1 mm
DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-97

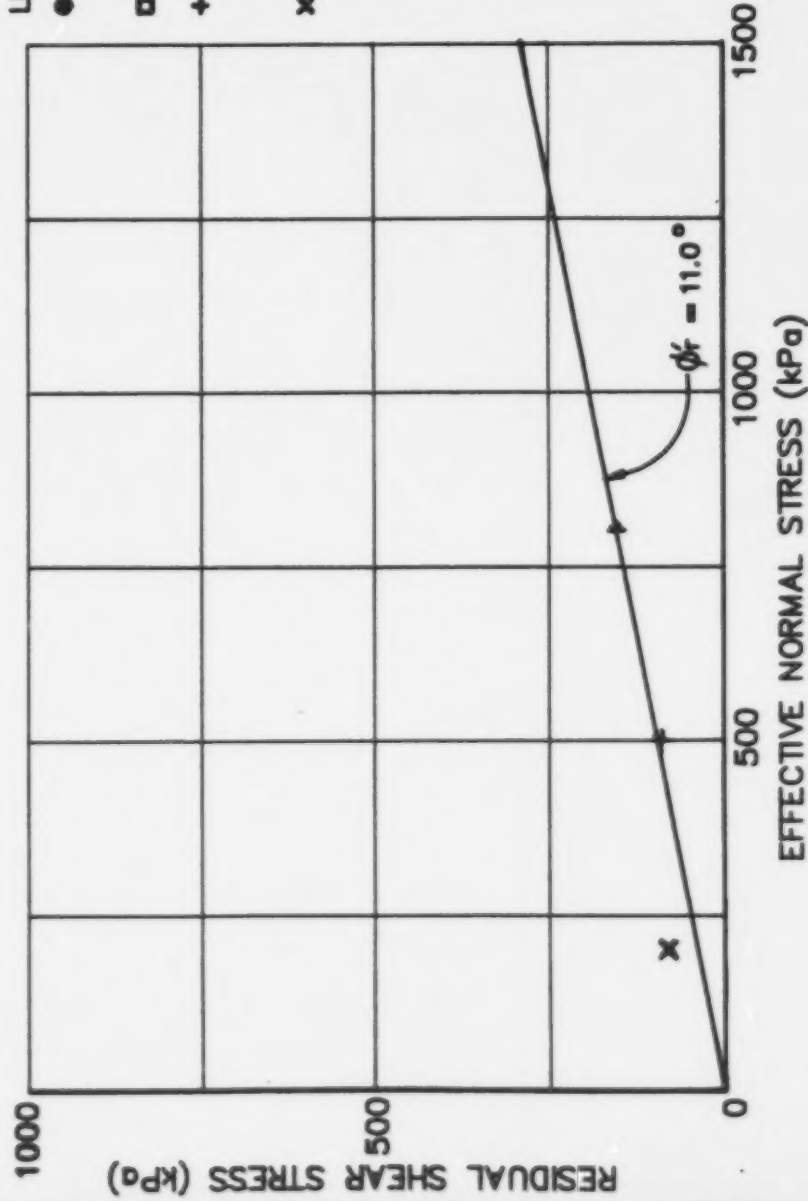
RESIDUAL SHEAR STRENGTH (INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES)

DRILL HOLE NO. = SH-86-S707

SAMPLE NO. = 108

DEPTH = 21.15

ELEVATION = 1114.23



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- +

SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST

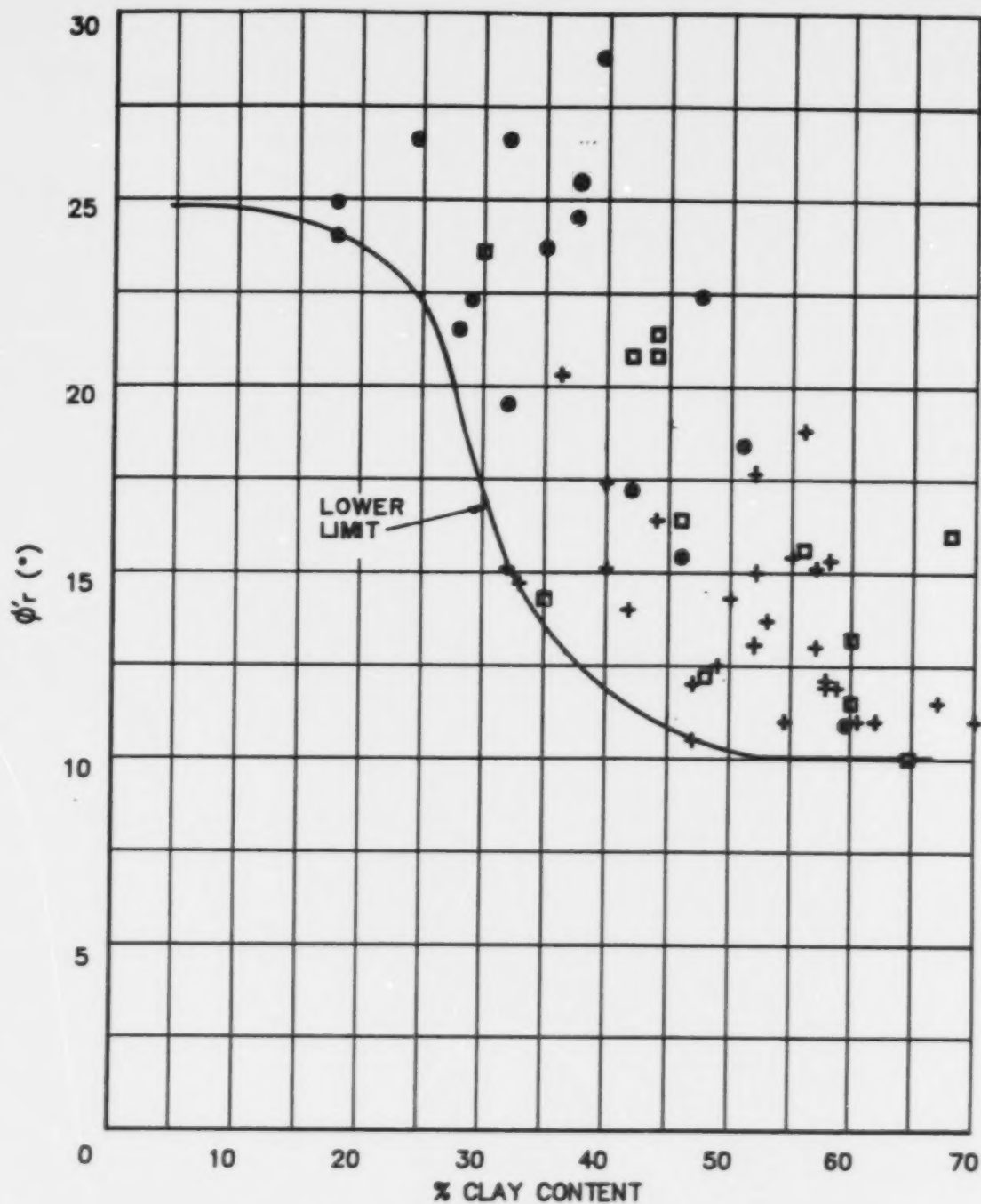
SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH 10 cm x 10 cm DIRECT SHEAR
TEST (SAMPLE REMAINED IN LATERAL
ALIGNMENT DURING TEST)

x - SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH 10 cm x 10 cm DIRECT SHEAR
TEST (SAMPLE MISALIGNED ≥ 1 mm
DURING TEST)



RESIDUAL SHEAR
STRENGTH-MOHR PLOT

PLATE B-98



FOR INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES
(COMBINED)

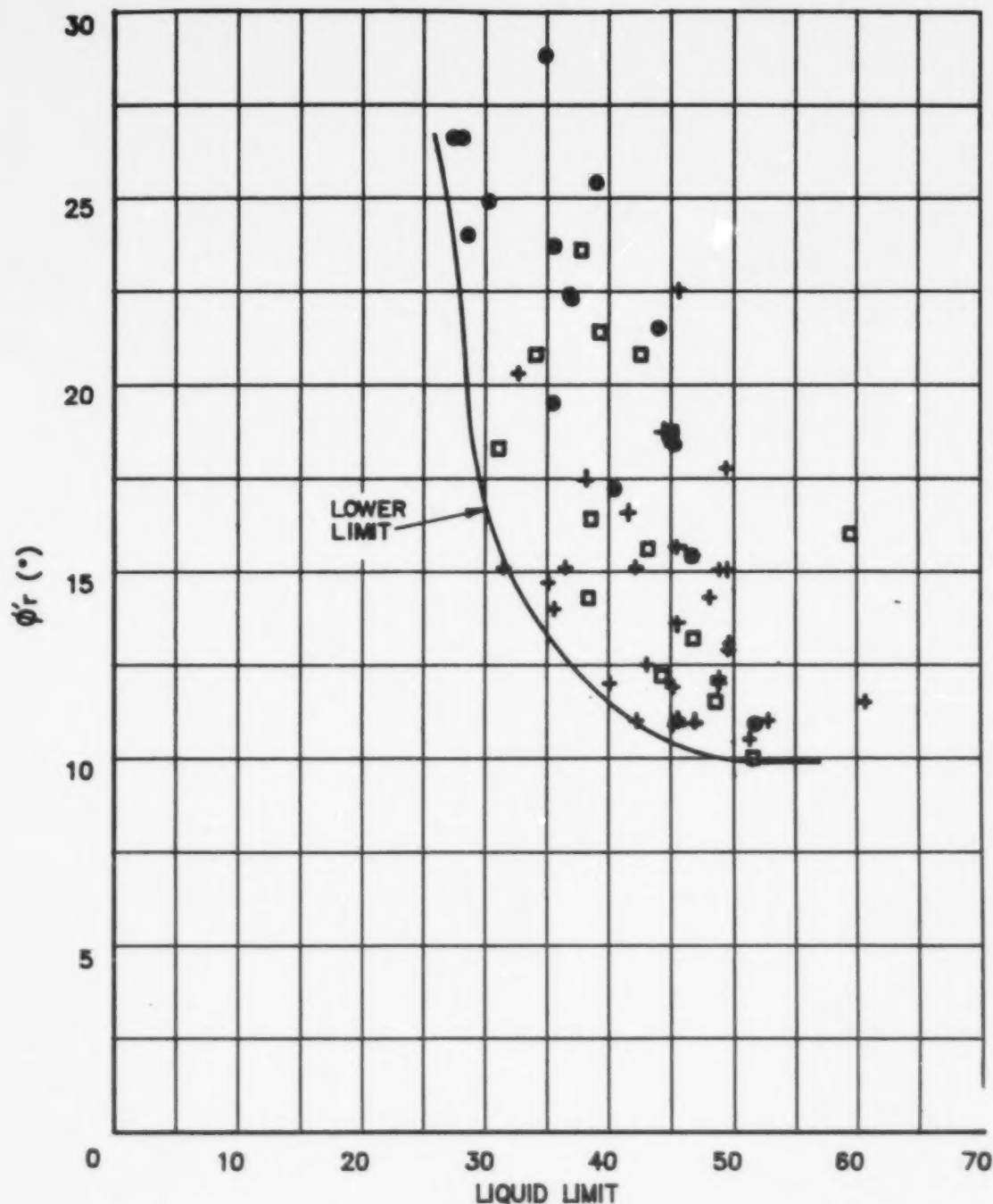
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
OR TRENCH

Abaco  
OLDMAN RIVER DAM

ϕ_r VS CLAY CONTENT

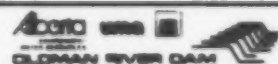
PLATE B-99



FOR INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES
(COMBINED)

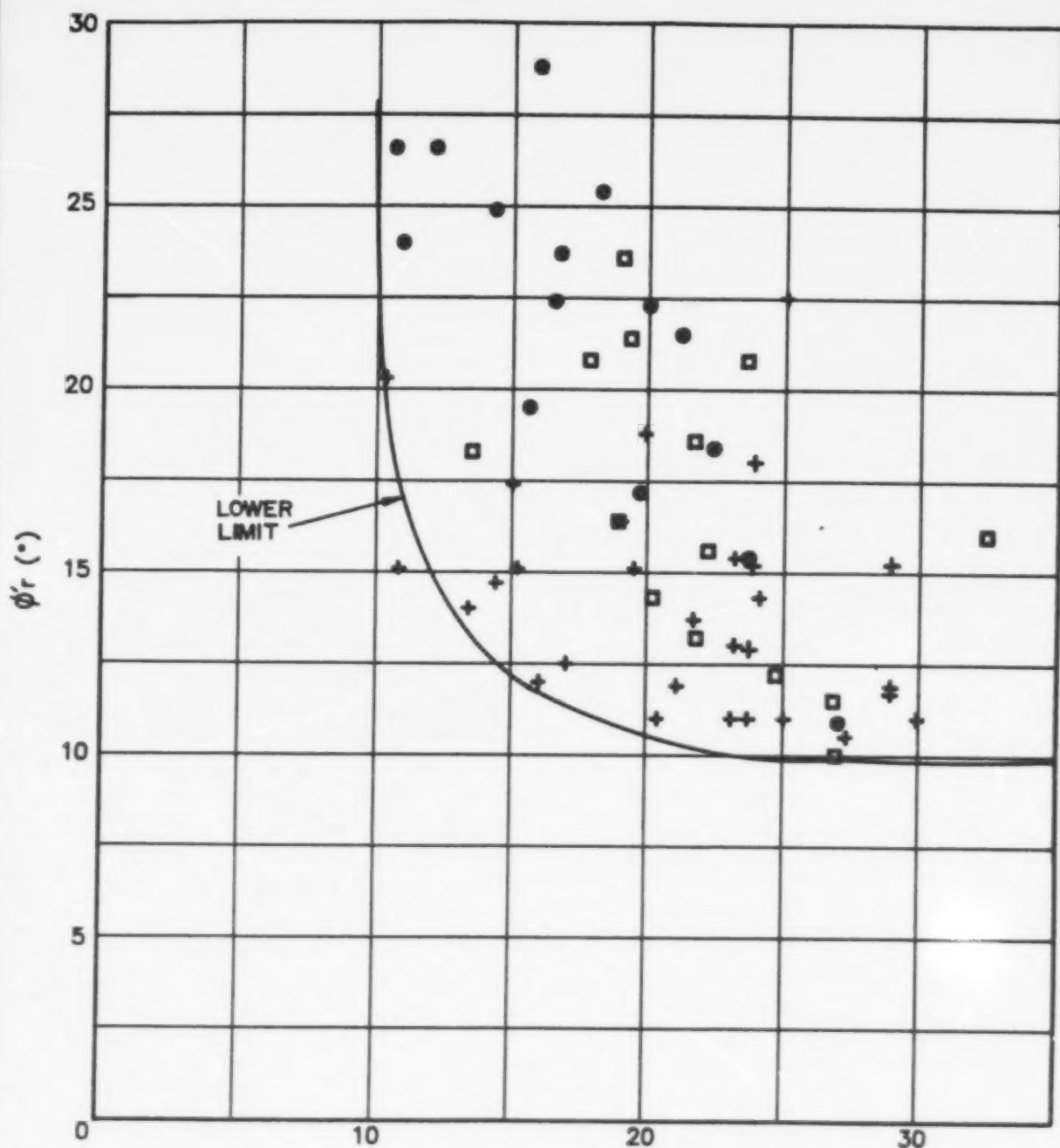
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
OR TRENCH



ϕ_r VS LIQUID LIMIT

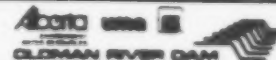
PLATE B-100



FOR INDIVIDUAL SEAMS OR CLAYSTONE SAMPLES
(COMBINED)

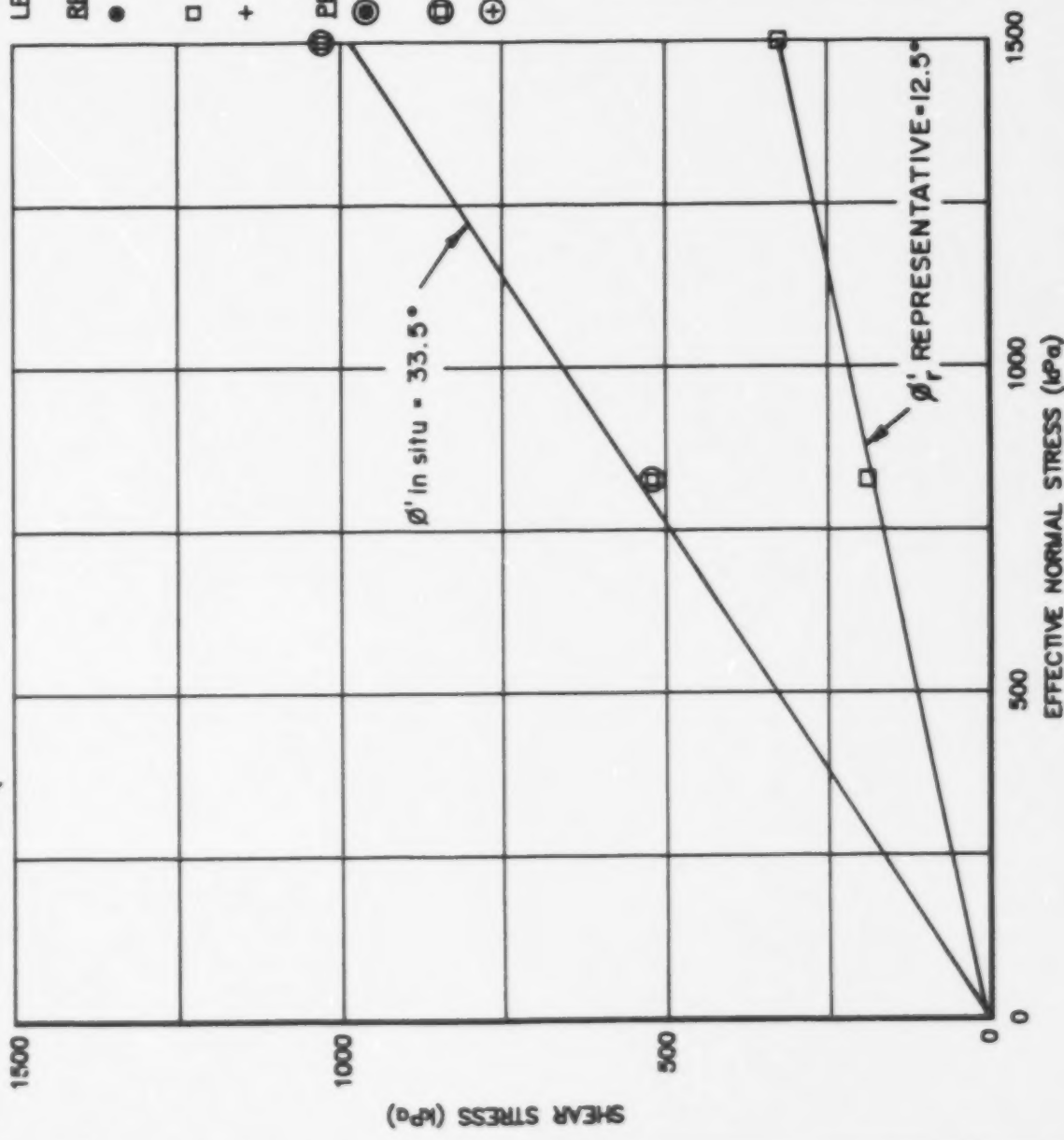
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- + - SEAM SAMPLE OBTAINED FROM SHAFT
10 cm x 10 cm DIRECT SHEAR TEST
OR TRENCH



ϕ_r VS PLASTICITY INDEX

PLATE B-101



LEGEND:

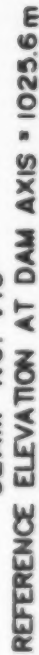
RESIDUAL

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
 - - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
 - ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.
- PEAK
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
 - ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
 - ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
42.7	20.0
REPRESENTATIVE VALUES	
43.0	20.0

SHEAR STRENGTH - IN SITU AND RESIDUAL
 SEAM NO. V8
 REFERENCE ELEVATION AT DAM AXIS = 1003.1 TO 1005.9 m

RESIDUAL SHEAR STRESS (MPa)



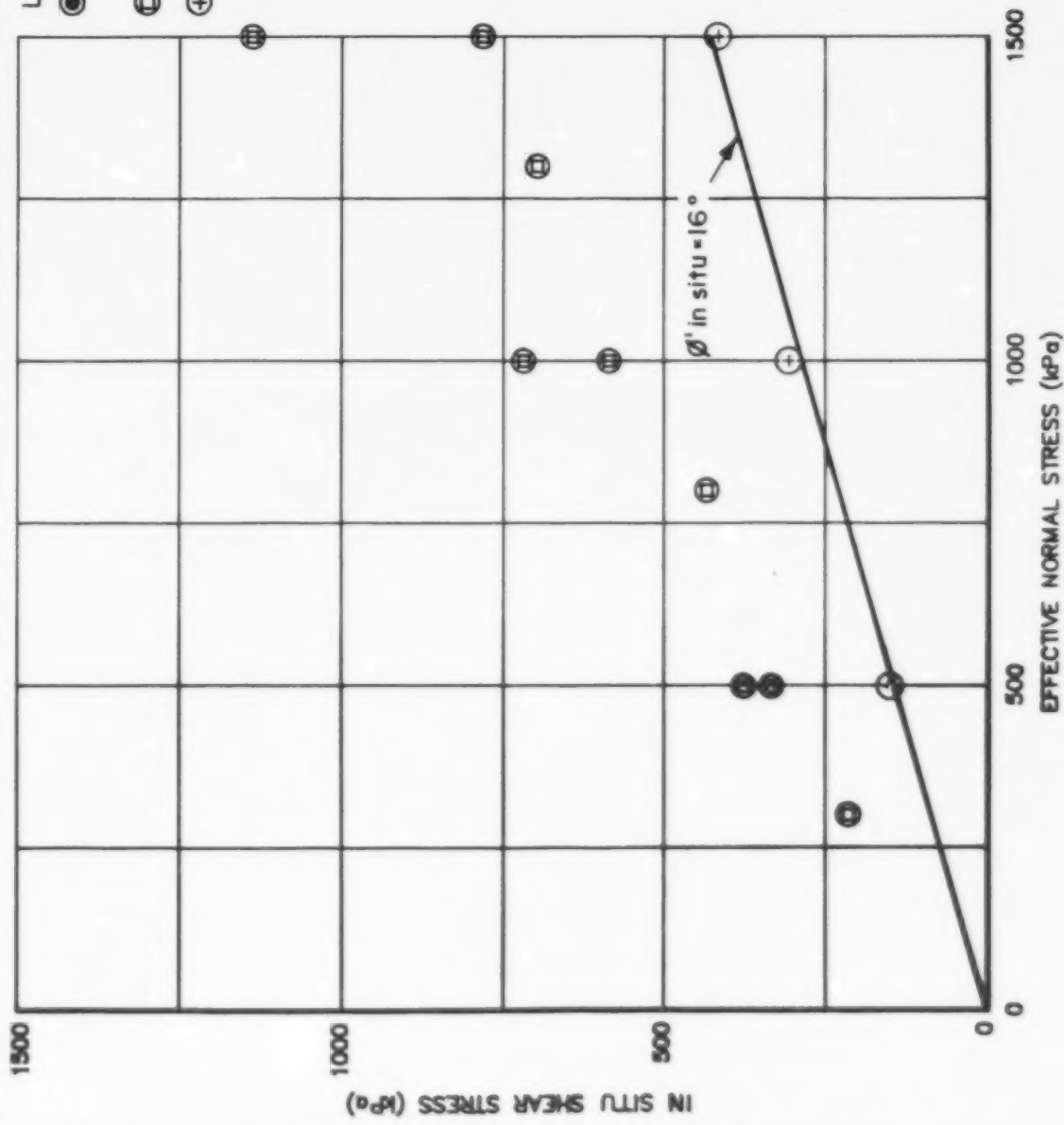
●	-	INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
□	-	SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
+	-	SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
34.0	42.0
35.0	33.0
46.7	60.0
38.3	18.1
REPRESENTATIVE VALUES	
40.0	37.0

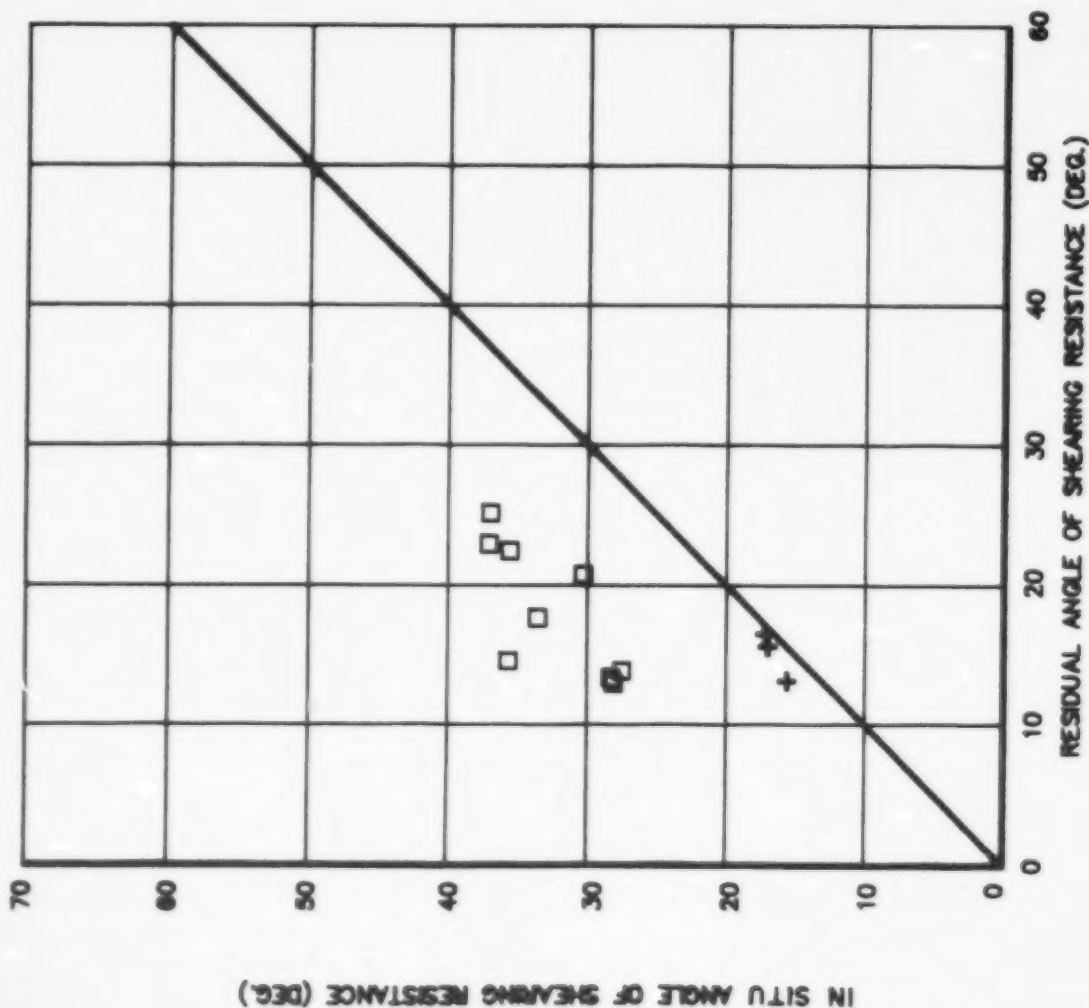


**SHEAR STRENGTH-RESIDUAL
SEAM VIO**

PLATE B-103



SHEAR STRENGTH - IN SITU
SEAM NO. V10
REFERENCE ELEVATION AT DAM AXIS = 1025.6 m



IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO. V10
REFERENCE ELEVATION AT DAM AXIS = 1025.6m

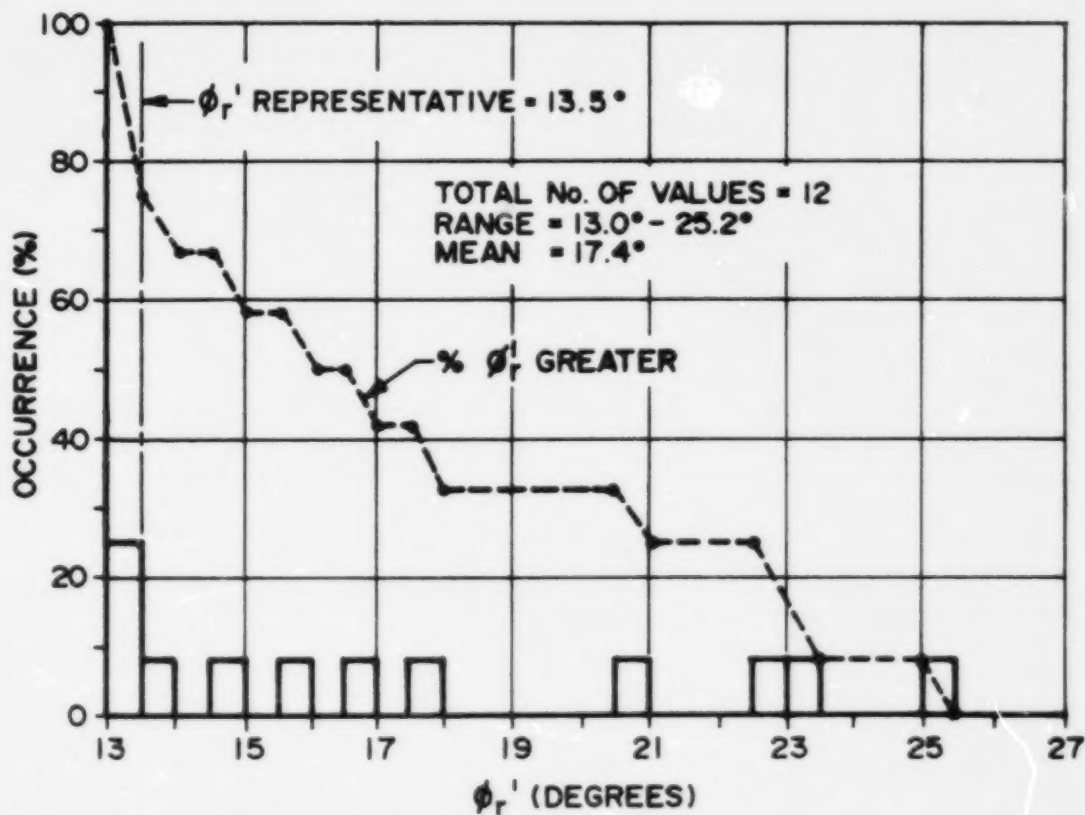
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

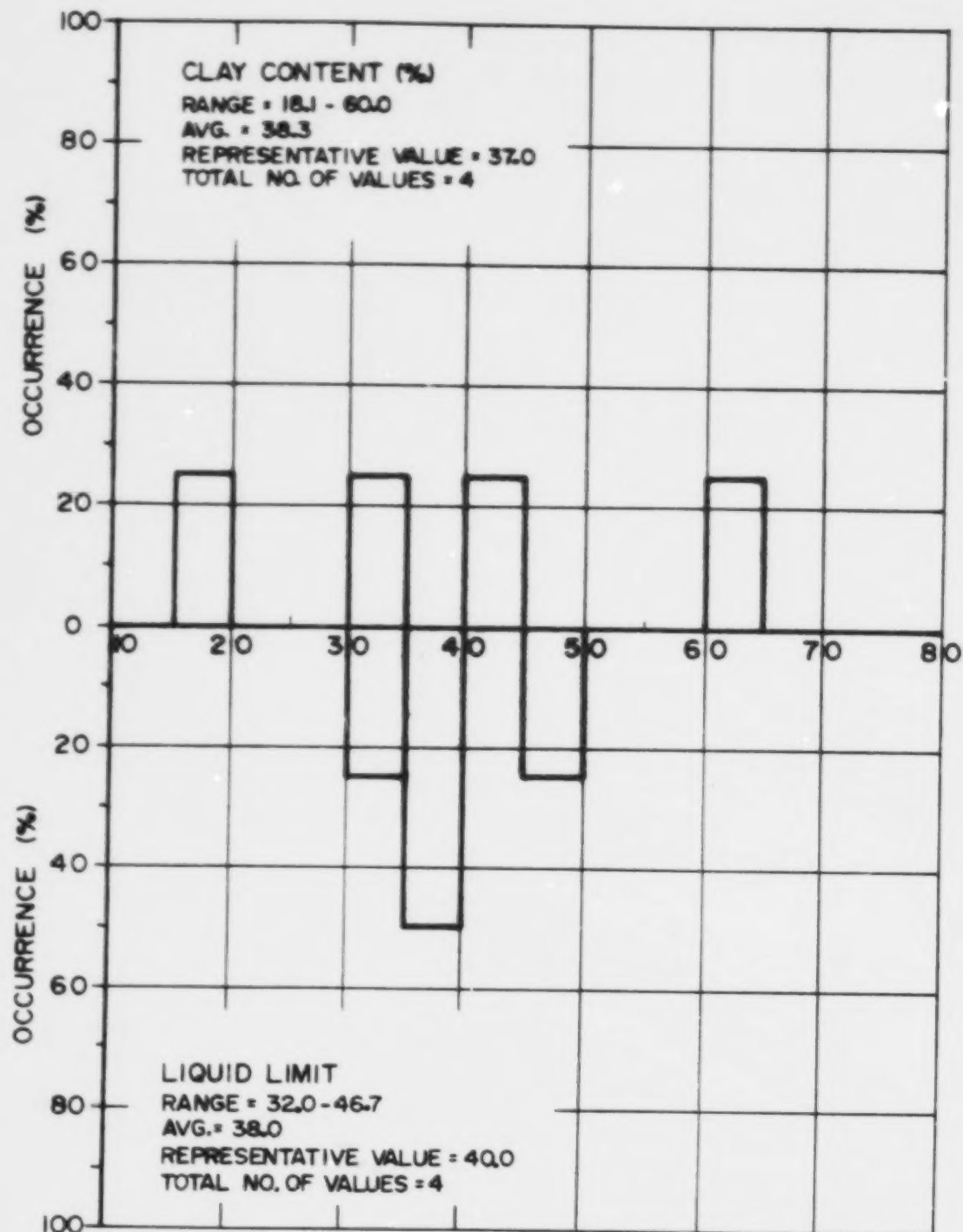


6' in situ vs 6';
SEAM V10

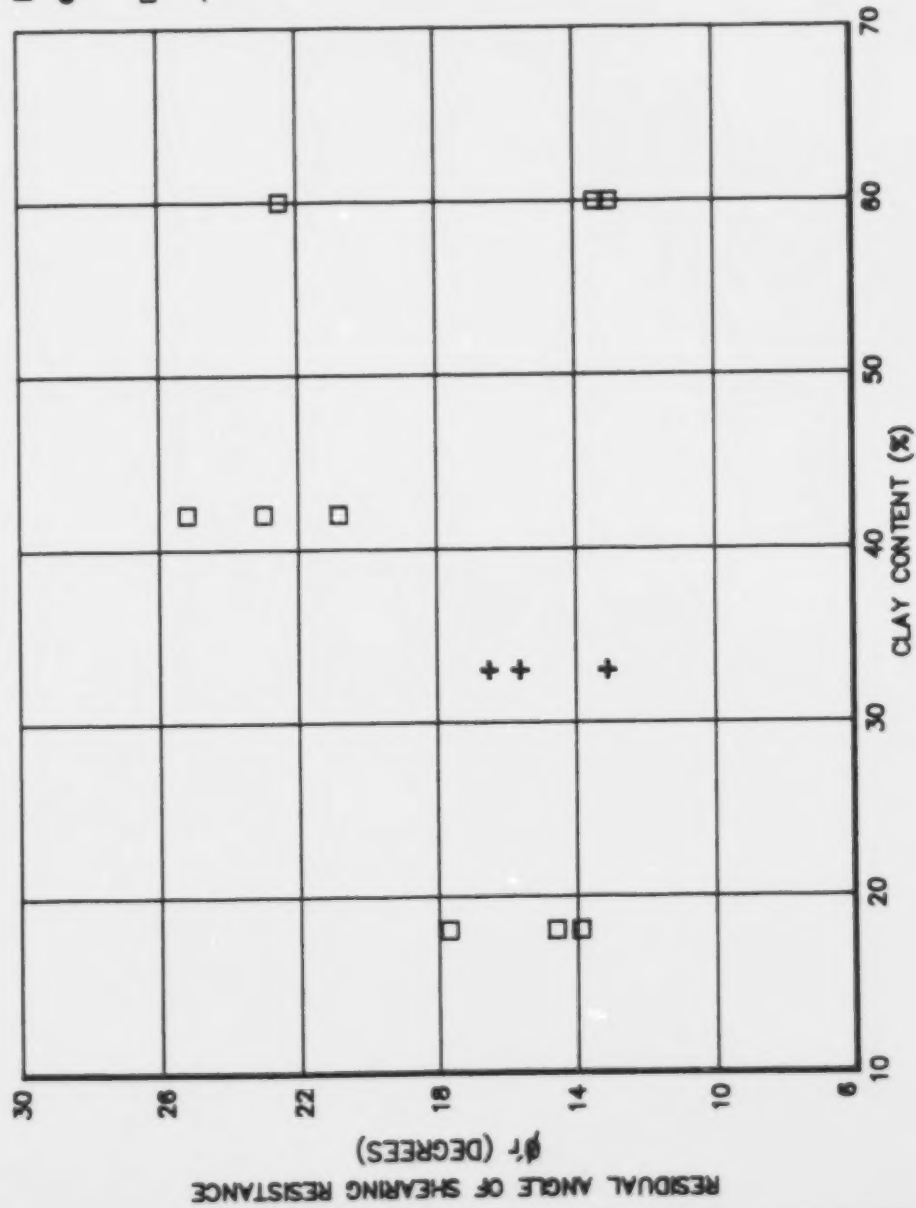
PLATE B-105



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM NO. V10
 REFERENCE ELEVATION AT DAM AXIS = 1025.6m



HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM NO. VIO
 REFERENCE ELEVATION AT DAM AXIS = 1025.6m

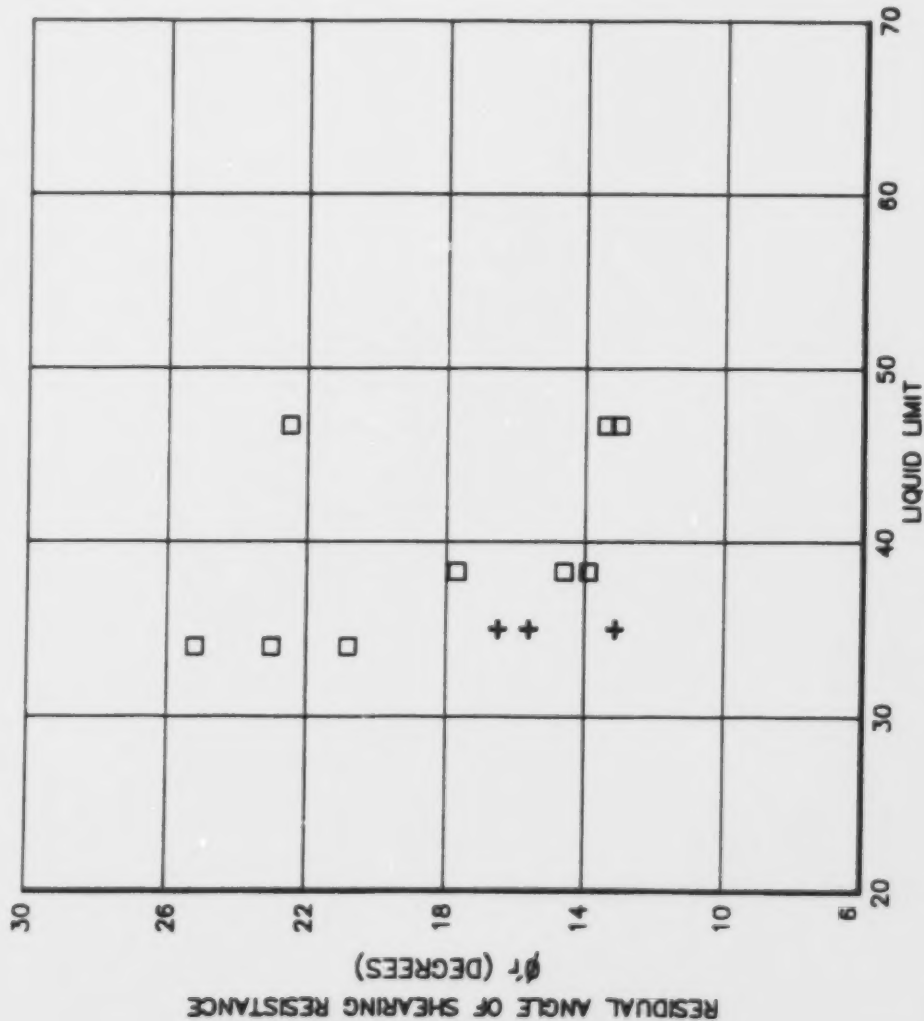


RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM NO. VIO
REFERENCE ELEVATION AT DAM AXIS = 1025.6 m



VS CLAY CONTENT
SEAM VIO

PLATE B-108



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- + - 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs LIQUID LIMIT
SEAM VIO

PLATE B-109

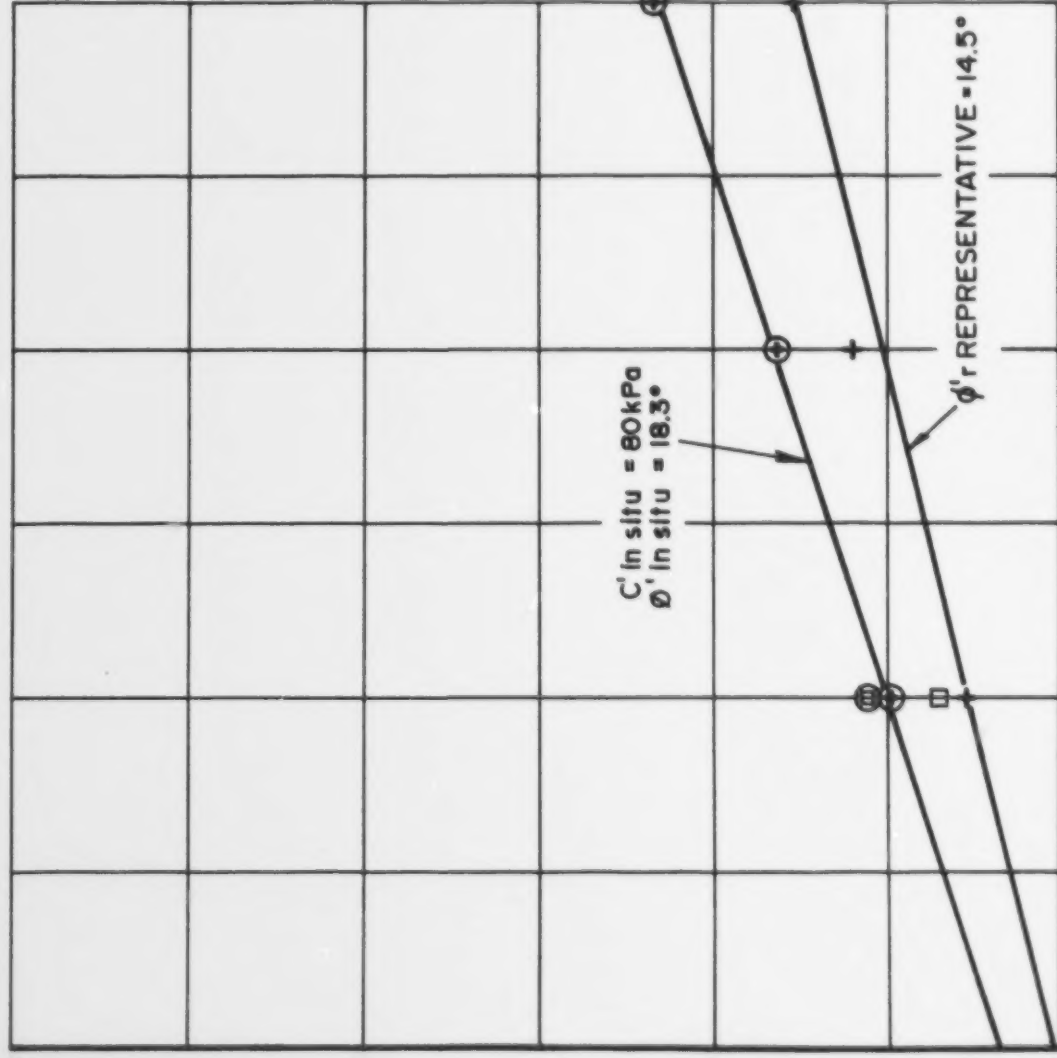
1500

1000

500

0

SHEAR STRESS (kPa)



1500

1000

500

EFFECTIVE NORMAL STRESS (kPa)

SHEAR STRENGTH - IN SITU AND RESIDUAL

SEAM NO. VII

REFERENCE ELEVATION AT DAM AXIS = 1027.6 m

LEGEND:

RESIDUAL

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

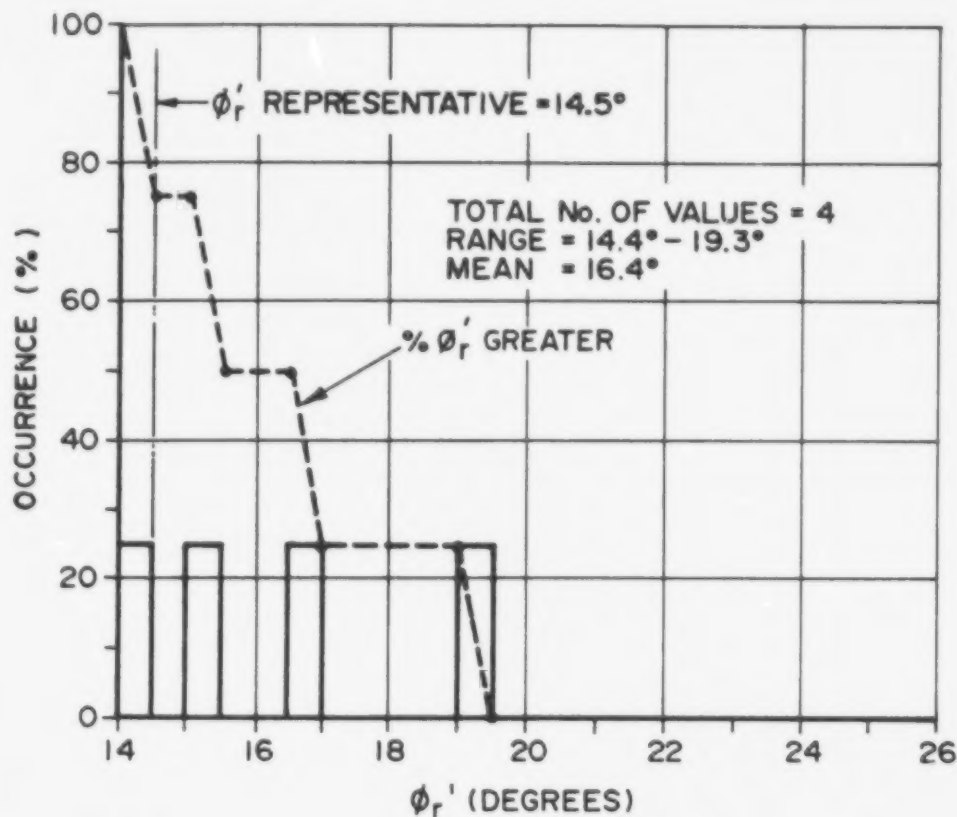
PEAK

- ⊙ - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊗ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

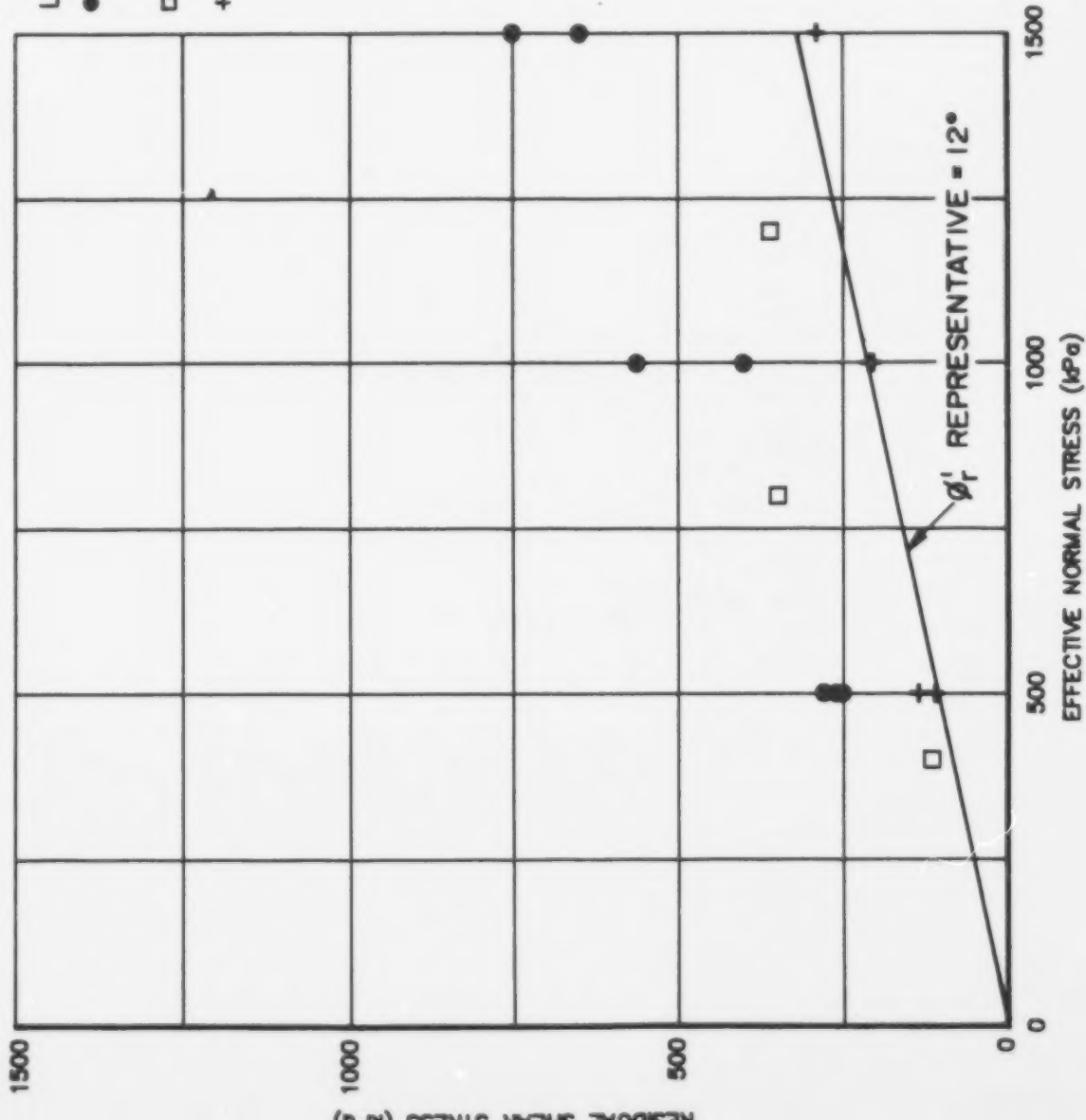
LL	C%
36.4	40.0
31.4	32.0
REPRESENTATIVE VALUES	
34.0	36.0

SHEAR STRENGTH
SEAM VII

PLATE B-110



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. VII
 REFERENCE ELEVATION AT DAM AXIS = 1027.6m



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- +

LL	C%
36.9	29.0
28.1	17.5
40.0	47.0
42.1	57.0
41.7	54.0
42.6	55.0
27.3	32.0
40.5	48.0
37.7	30.0
36.5	44.0
REPRESENTATIVE VALUES	
42.0	51.0



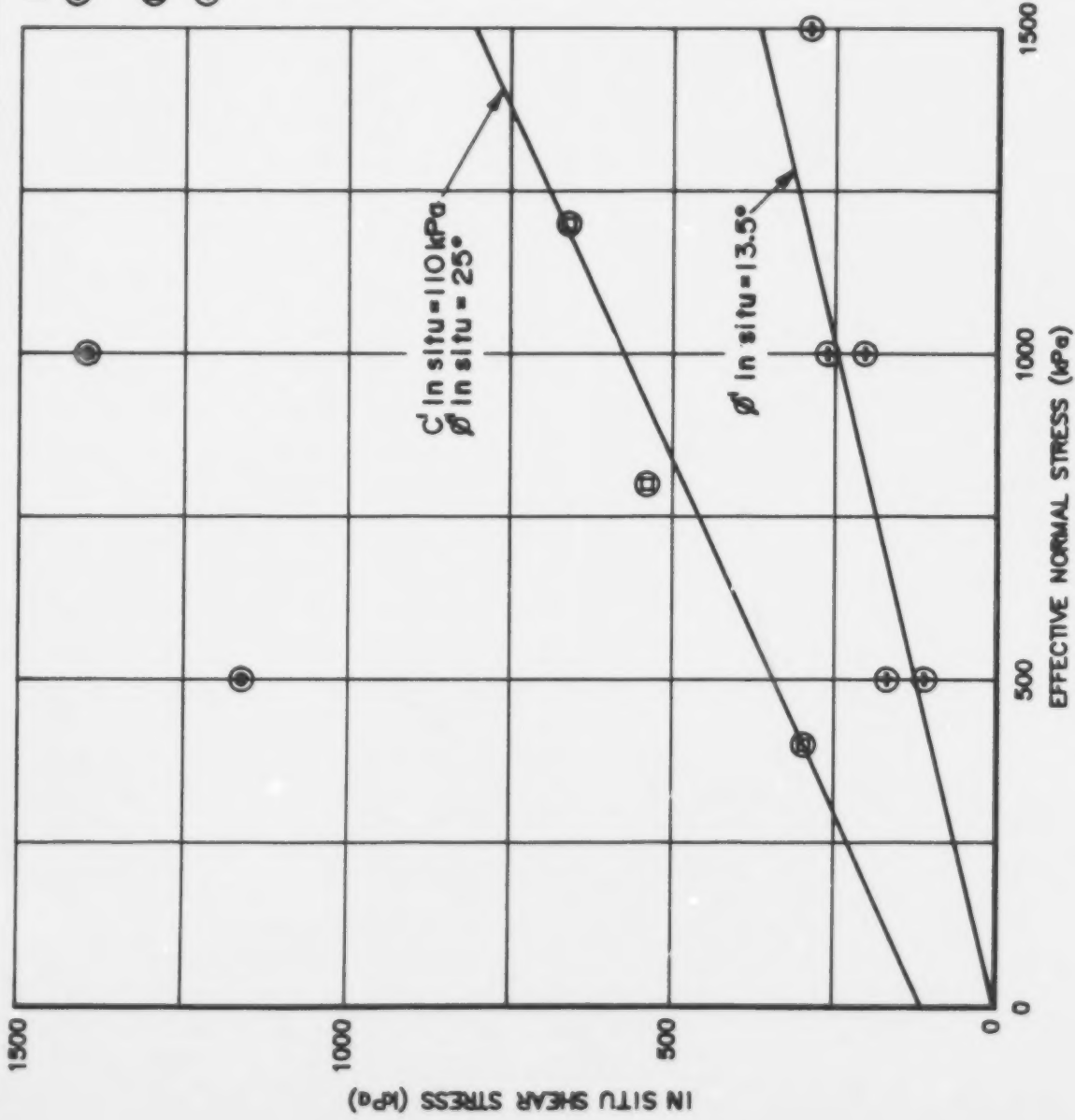
SHEAR STRENGTH - RESIDUAL
SEAM V12

PLATE B-112

SHEAR STRENGTH - RESIDUAL
SEAM No. V12
REFERENCE ELEVATION AT DAM AXIS = 1030.7m

LEGEND:

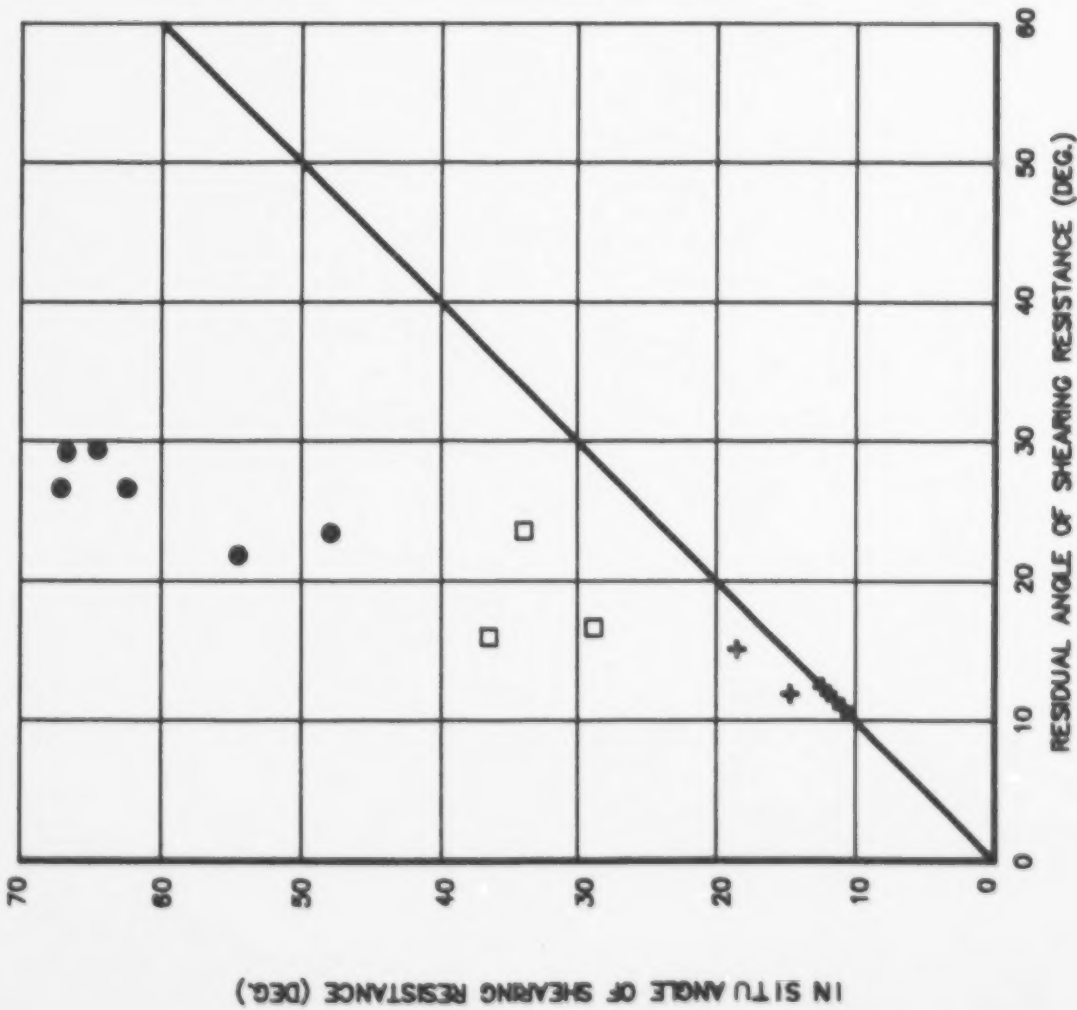
- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH, 10 cm x 10 cm DIRECT SHEAR
TEST.



SHEAR STRENGTH - IN SITU
SEAM V12

REFERENCE ELEVATION AT DAM AXIS = 1030.7 m

PLATE B-113



IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM No V12
REFERENCE ELEVATION AT DAM AXIS = 1030.7m

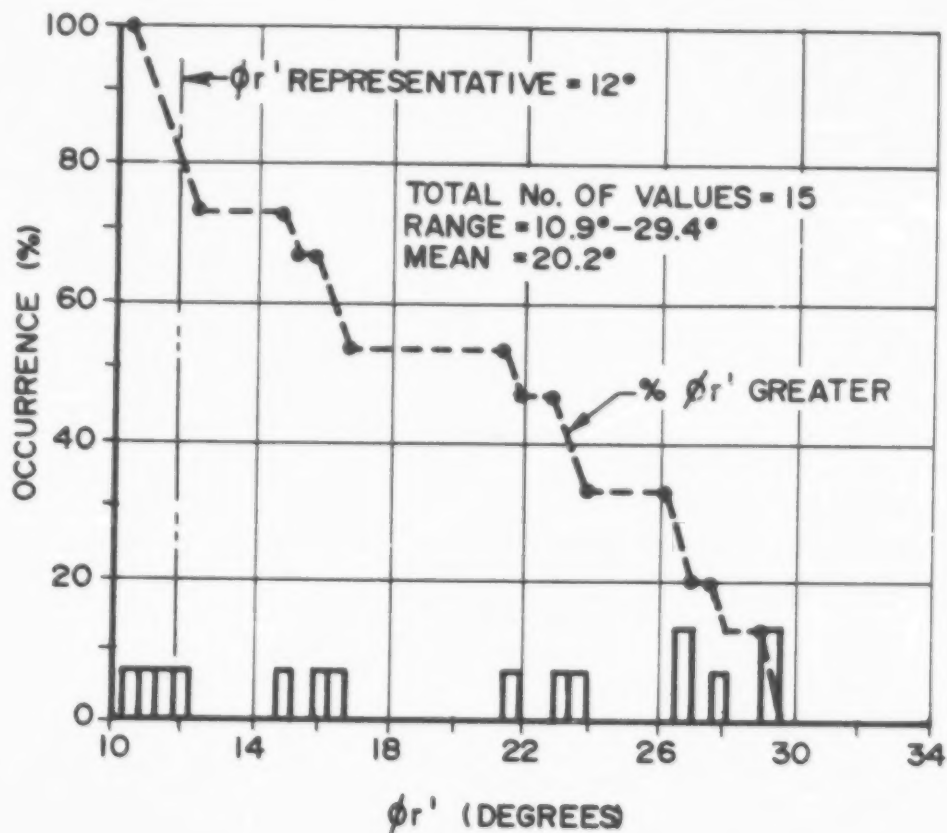
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +

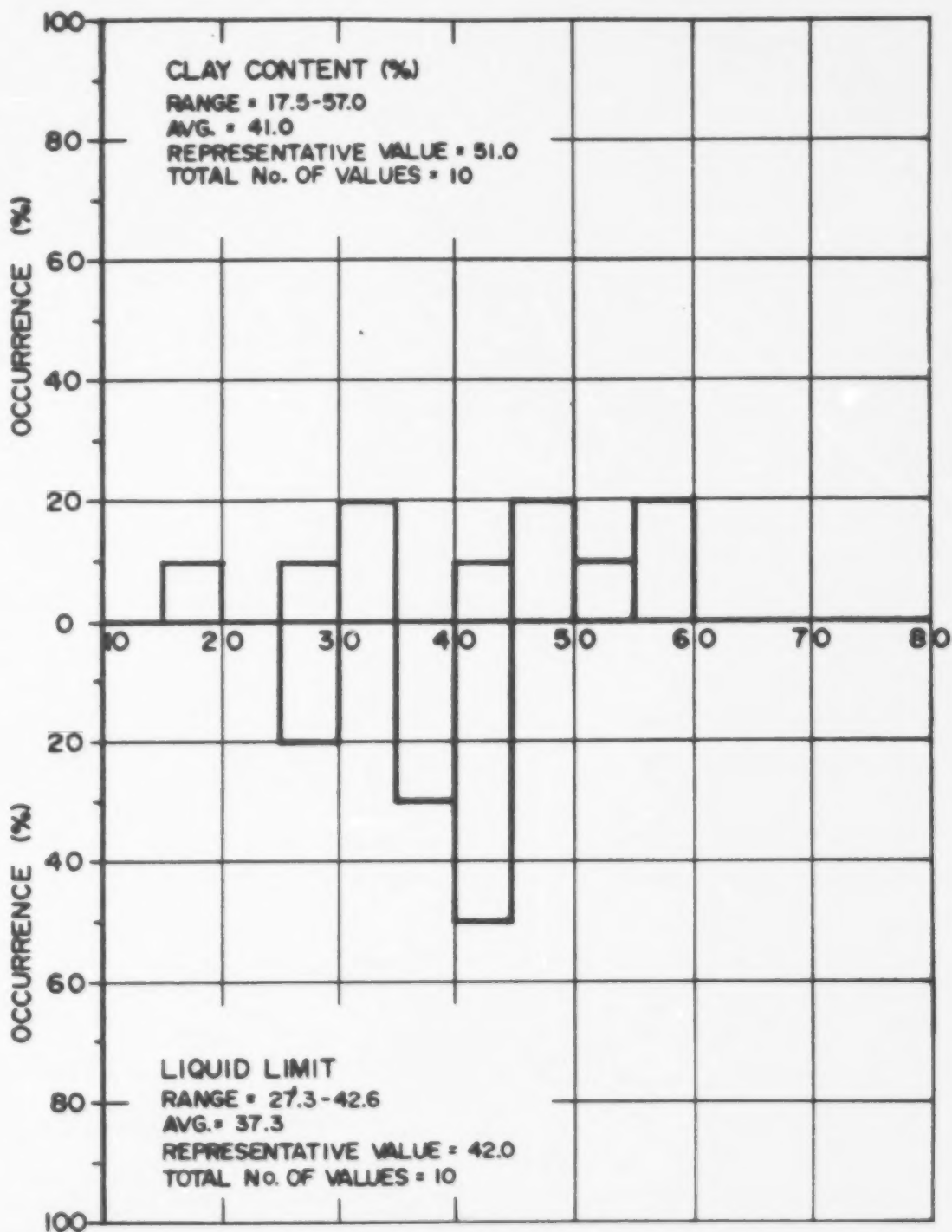


IN SITU VS ϕ'
SEAM V12

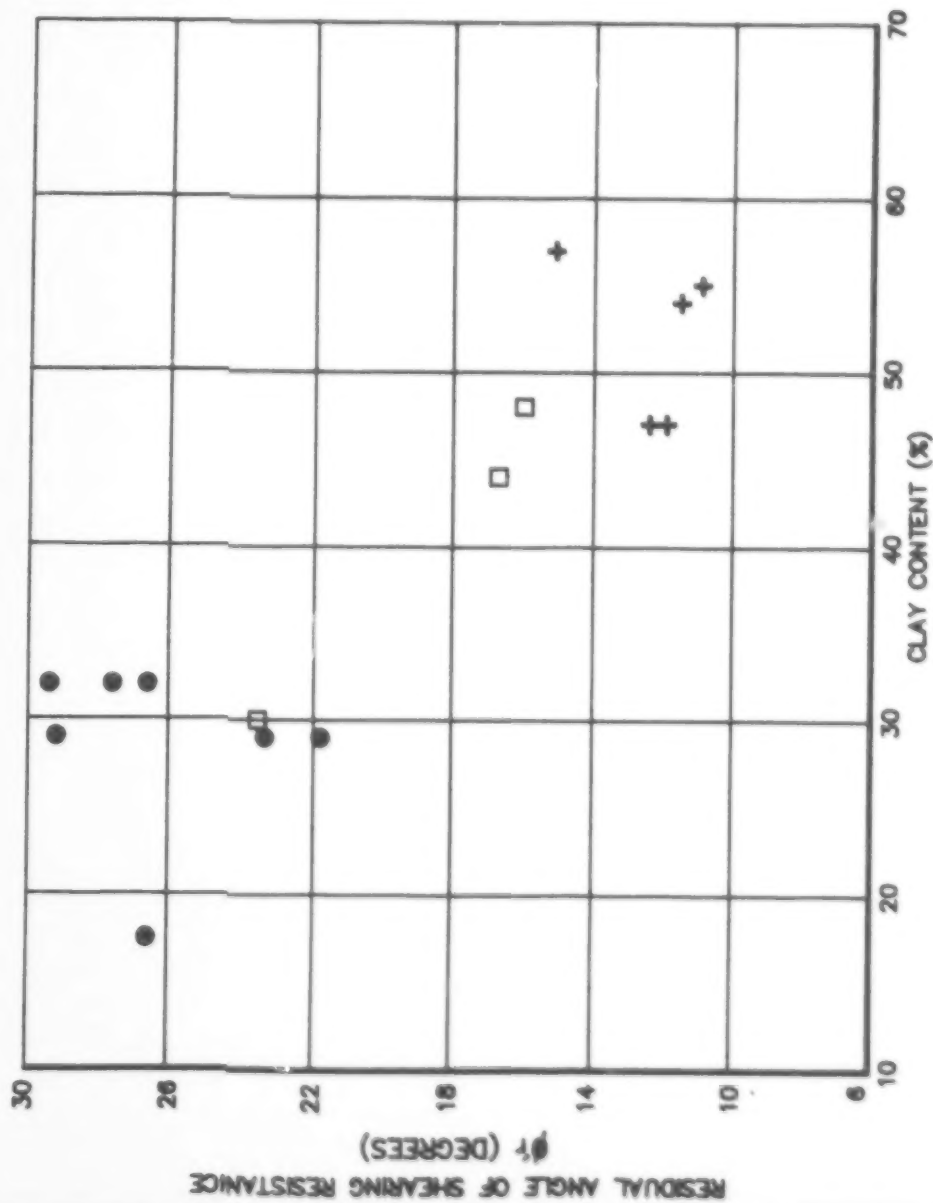
PLATE B-114



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. V12
 REFERENCE ELEVATION AT DAM AXIS = 1030.7m



**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM No. VI2
 REFERENCE ELEVATION AT DAM AXIS = 1030.7m**



RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM No. V12
REFERENCE ELEVATION AT DAM AXIS = 1030.7 m

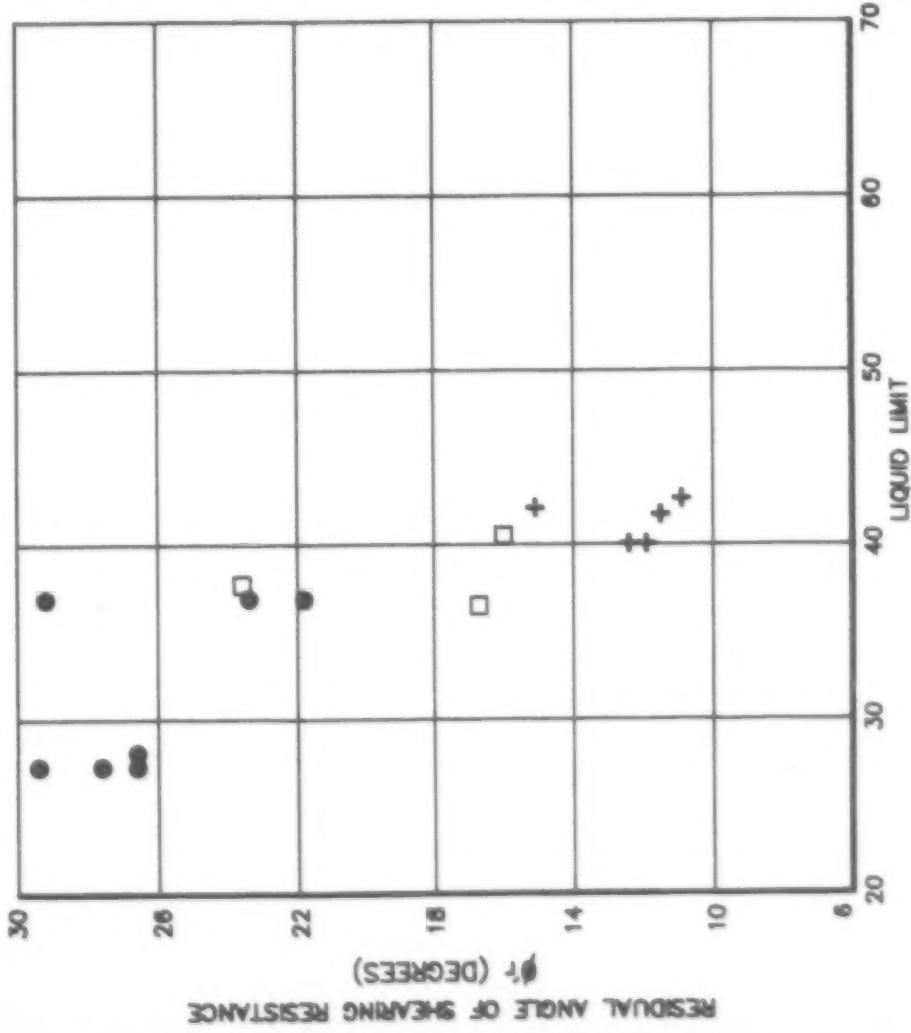
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



VS CLAY CONTENT
SEAM V12

PLATE B-117

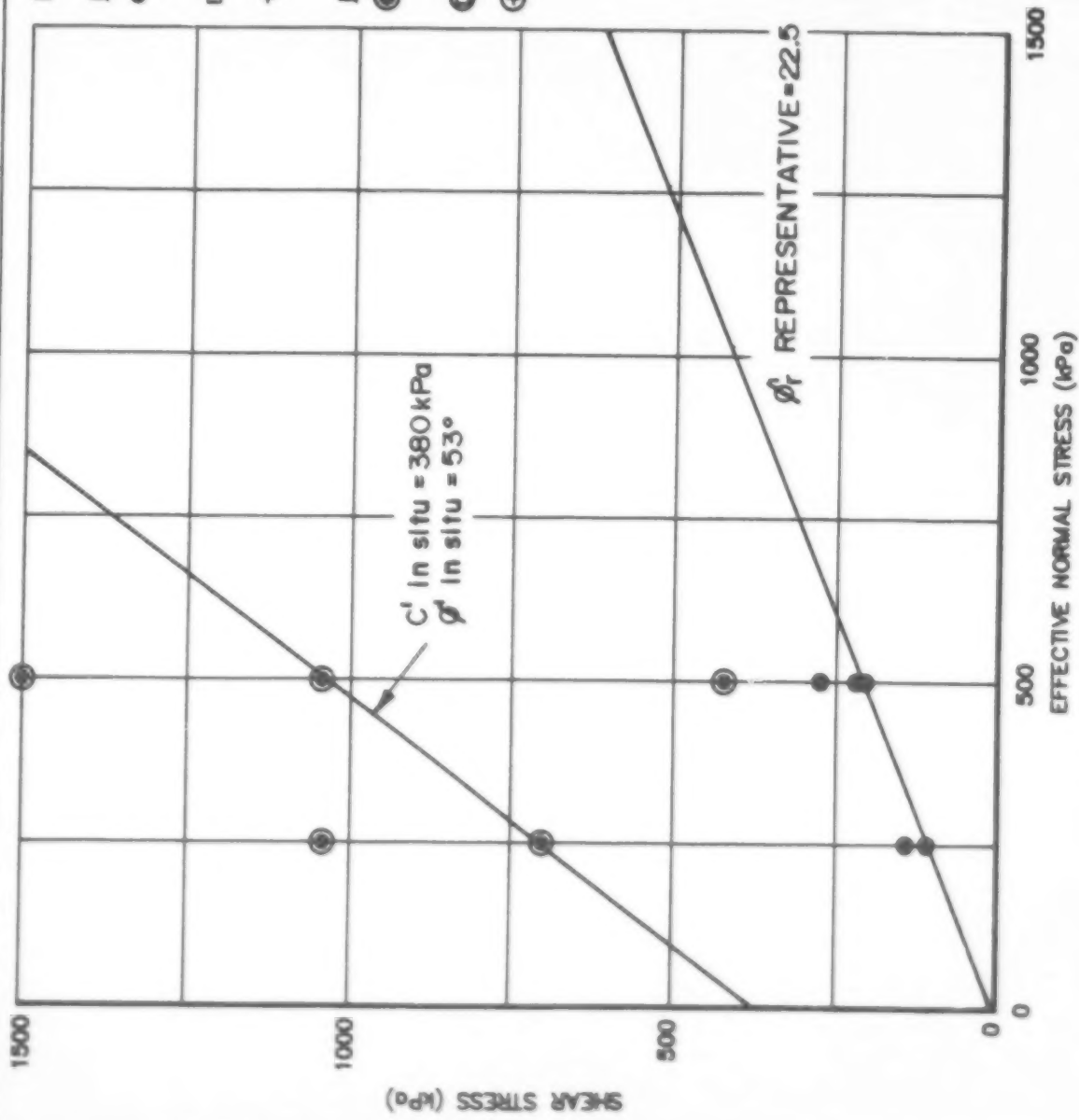


RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM No. VI2
REFERENCE ELEVATION AT DAM AXIS = 1030.7 m



ϕ_r vs LIQUID LIMIT
SEAM VI2

PLATE B-118



LEGEND:

RESIDUAL

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

PEAK

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
36.7	47.5
35.5	35.0
34.8	30.5
REPRESENTATIVE VALUES	
36.0	40.0

500 1000 1500
EFFECTIVE NORMAL STRESS (kPa)

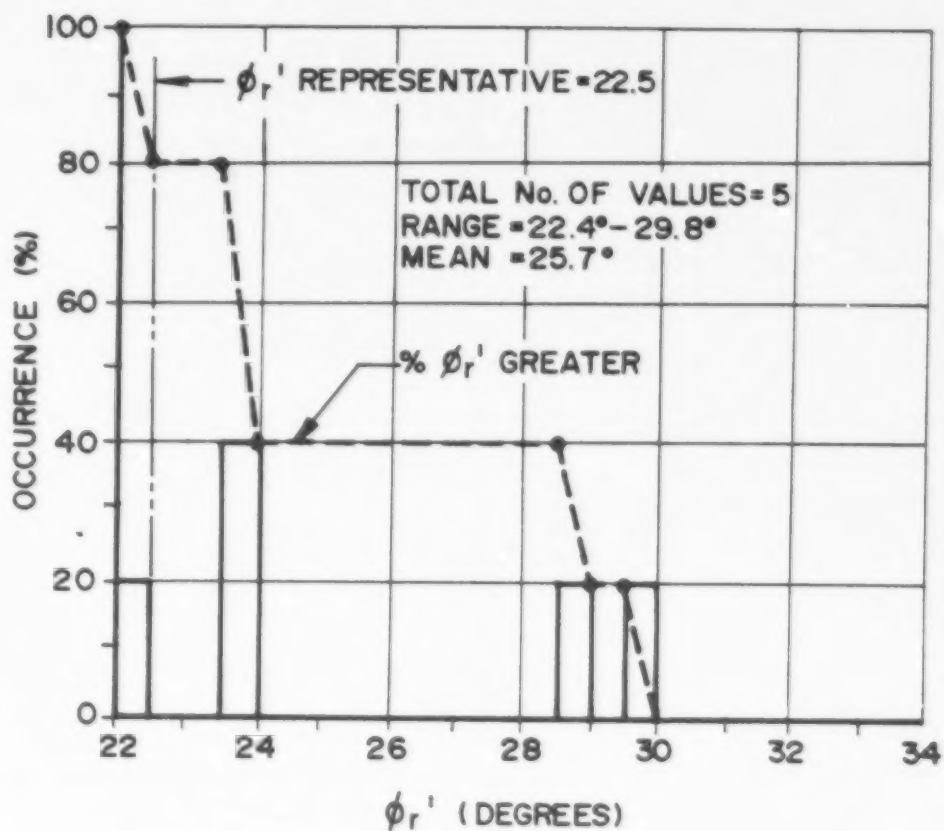
SHEAR STRENGTH - IN SITU AND RESIDUAL
SEAM No. V15

REFERENCE ELEVATION AT DAM AXIS = 1043.9 m

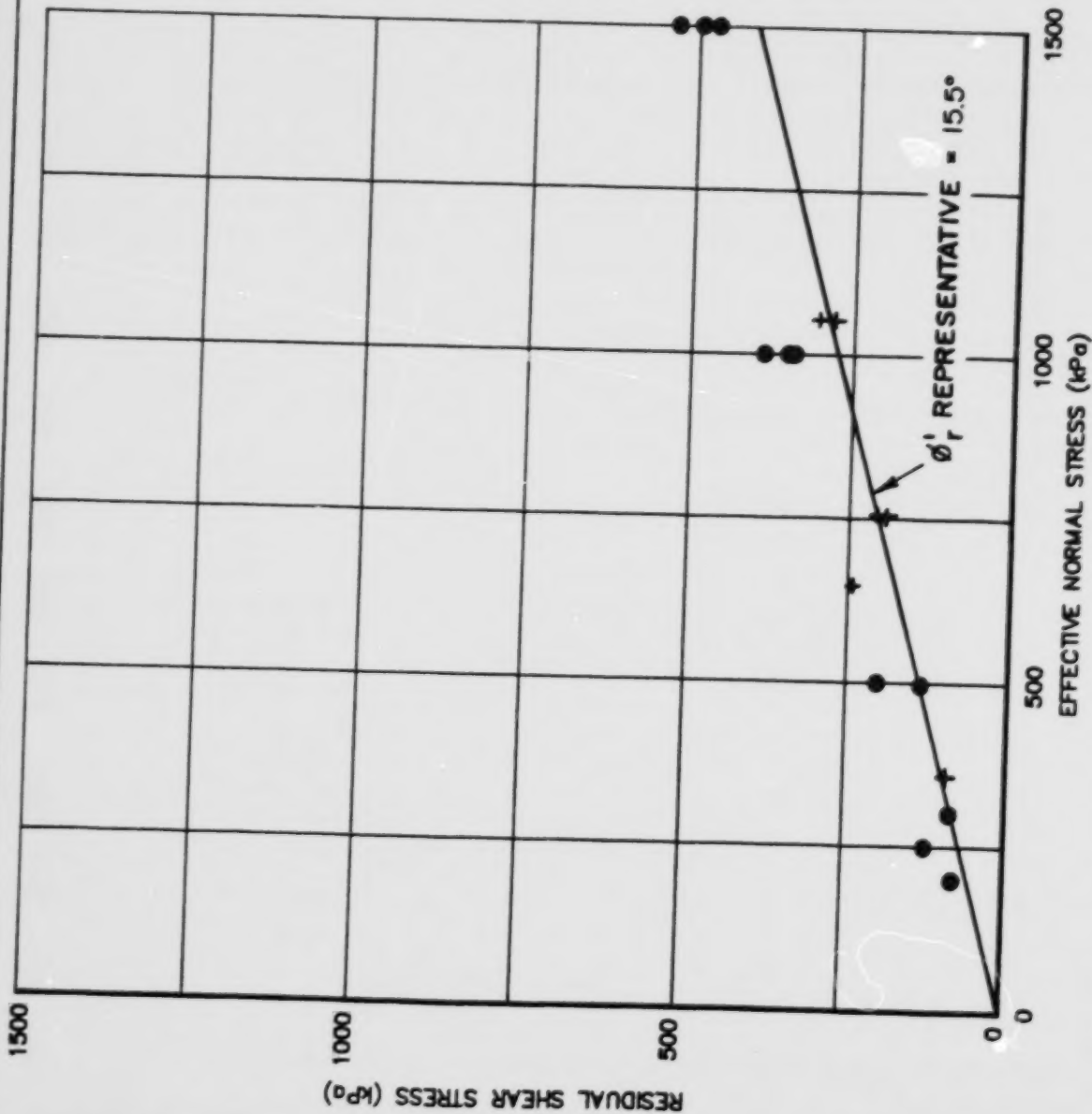


SHEAR STRENGTH
SEAM V15

PLATE B-119



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. VI5
 REFERENCE ELEVATION AT DAM AXIS = 1043.9m



LL	C%
46.6	46.0
35.4	32.0
47.5	—
44.4	—
REPRESENTATIVE VALUES	
41.0	39.0

EFFECTIVE NORMAL STRESS (kPa)

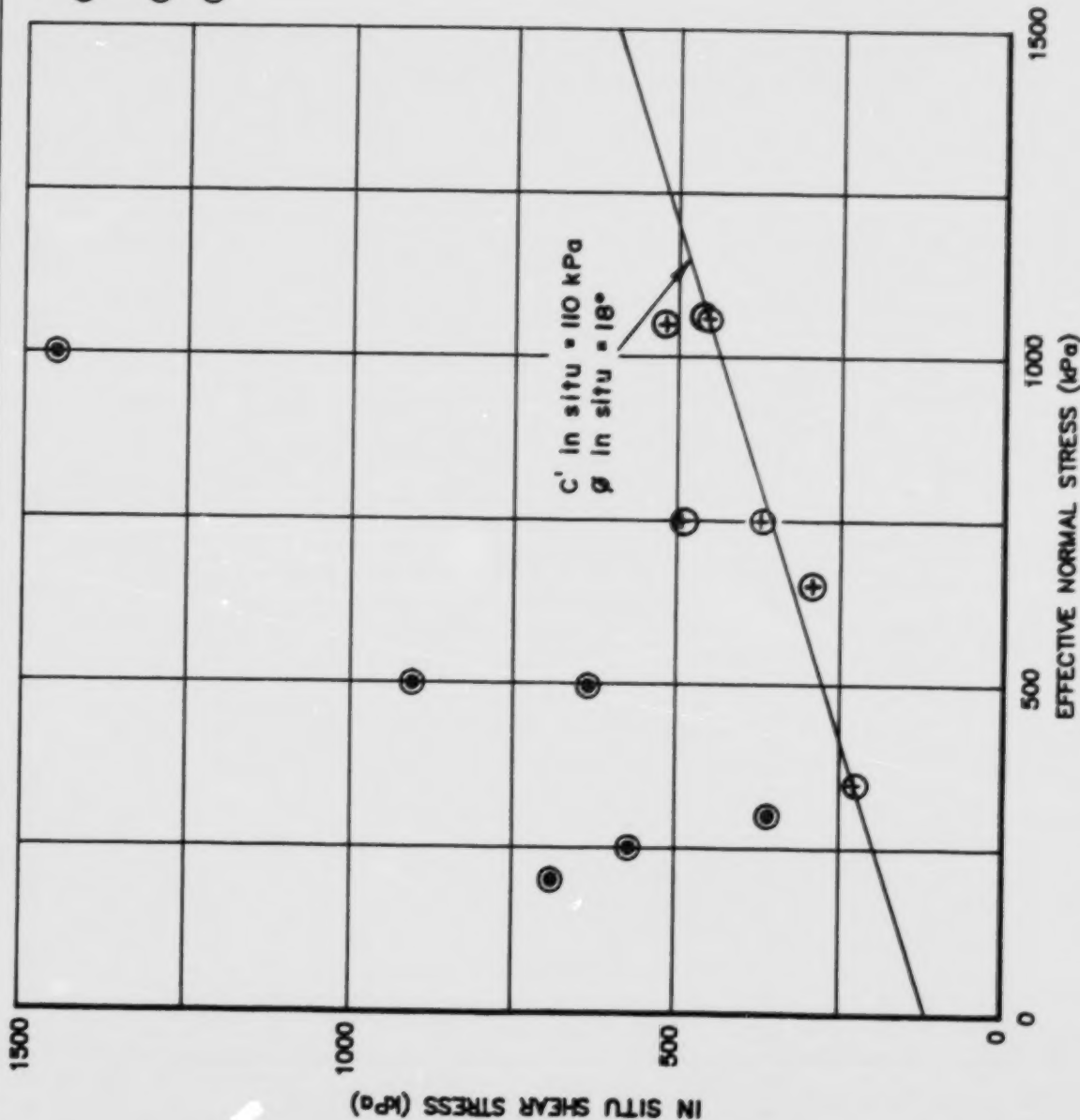
SHEAR STRENGTH - RESIDUAL
SEAM NO. V16

SLAM NO. VIB
REFERENCE ELEVATION AT DAM AXIS = 1046.8 m



**SHEAR STRENGTH-RESIDUAL
SEAM VI6**

PLATE B-121



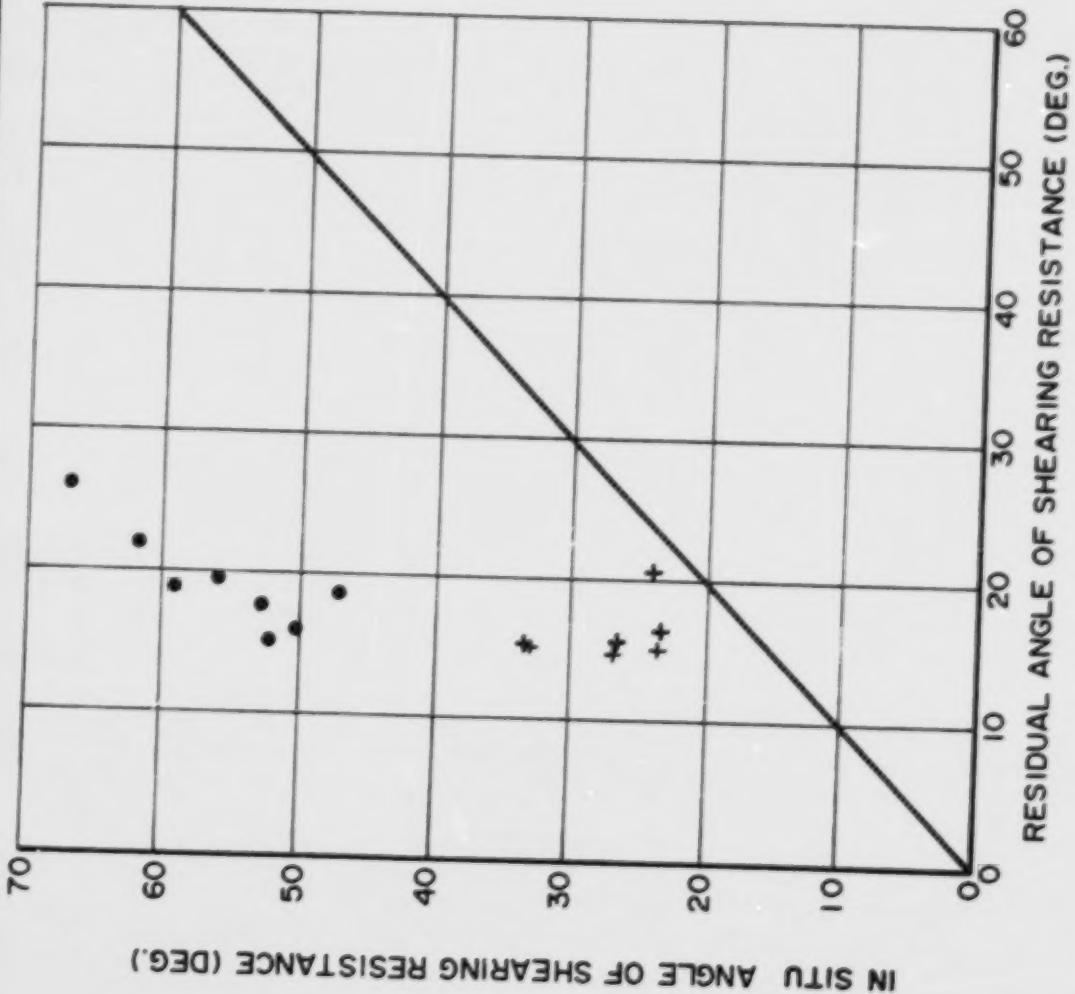
SHEAR STRENGTH - IN SITU
SEAM NO. VI6

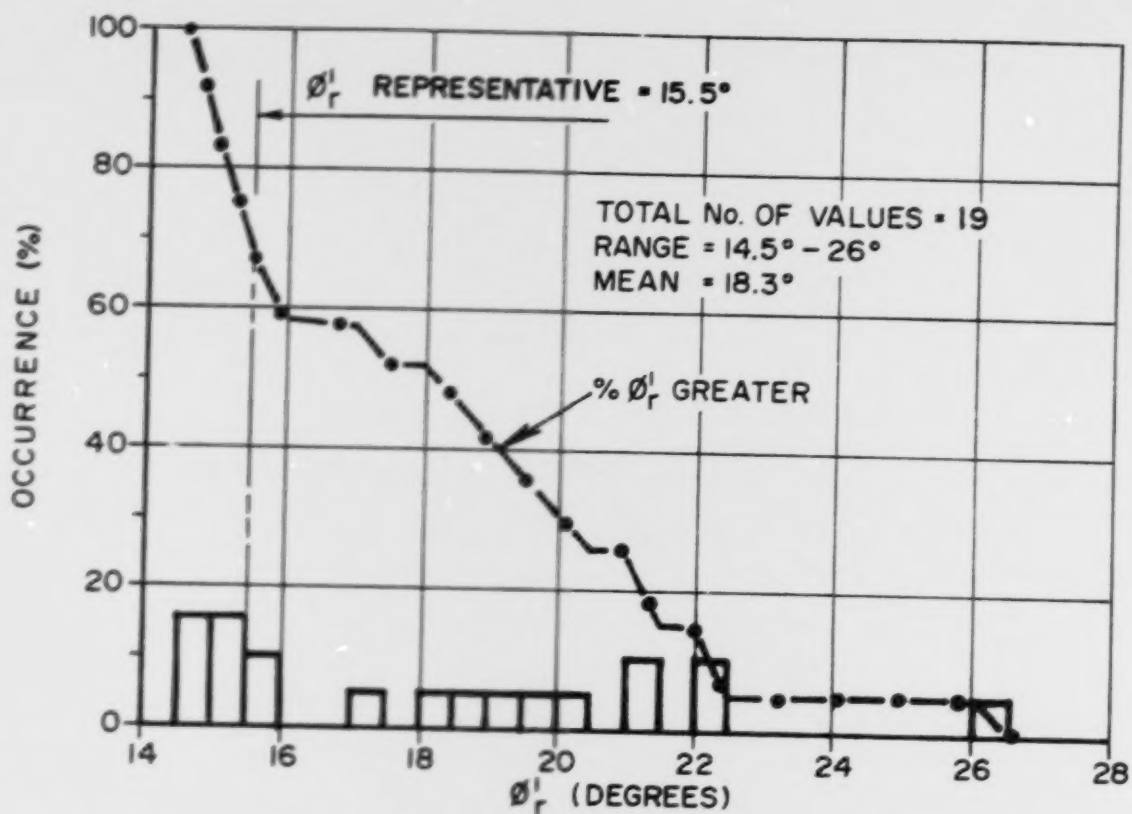
REFERENCE ELEVATION AT DAM AXIS = 1046.8 m



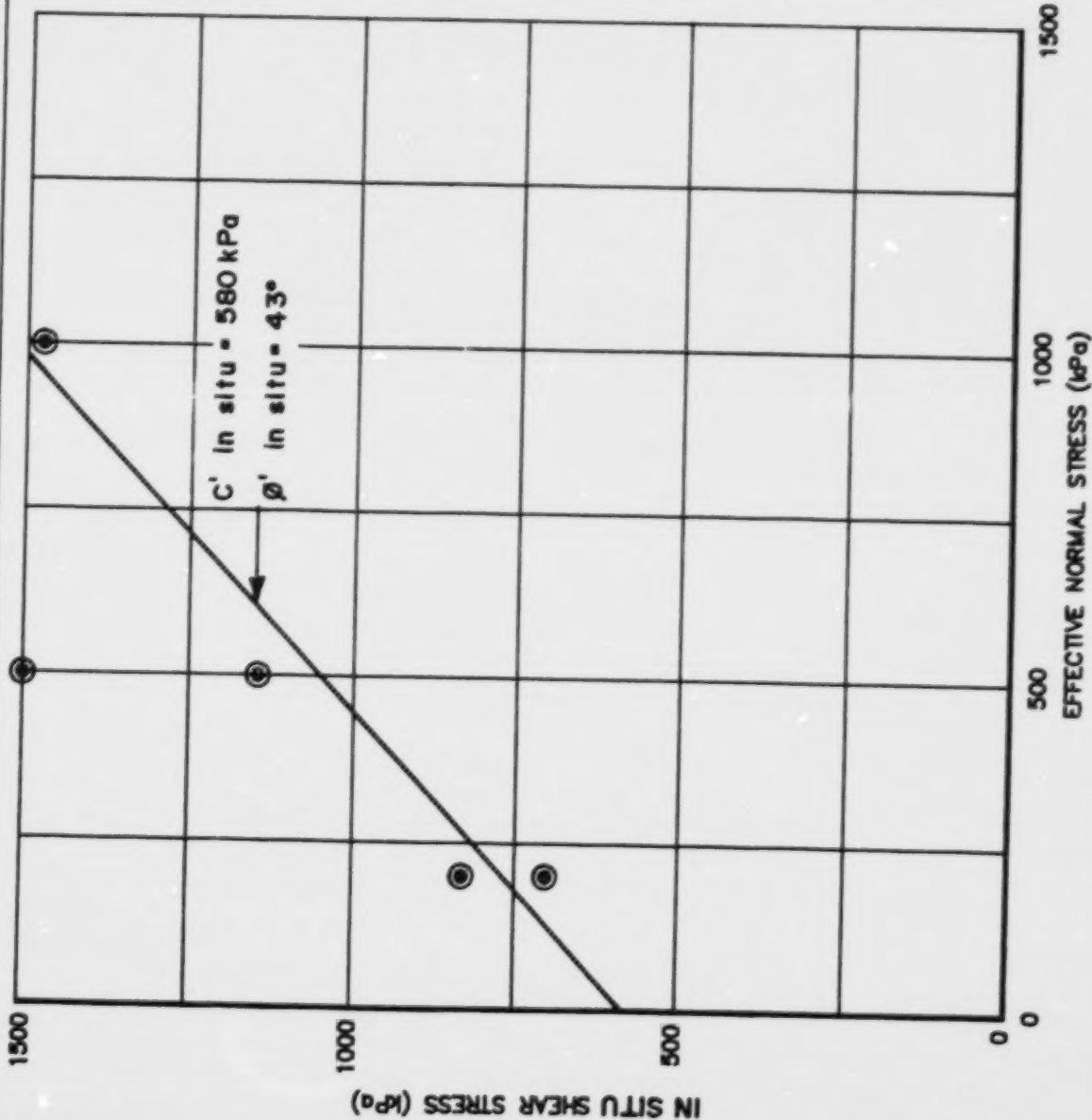
SHEAR STRENGTH - IN SITU
SEAM VI6

PLATE B-122





HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. V16
 REFERENCE ELEVATION AT DAM AXIS = 1046.8 m



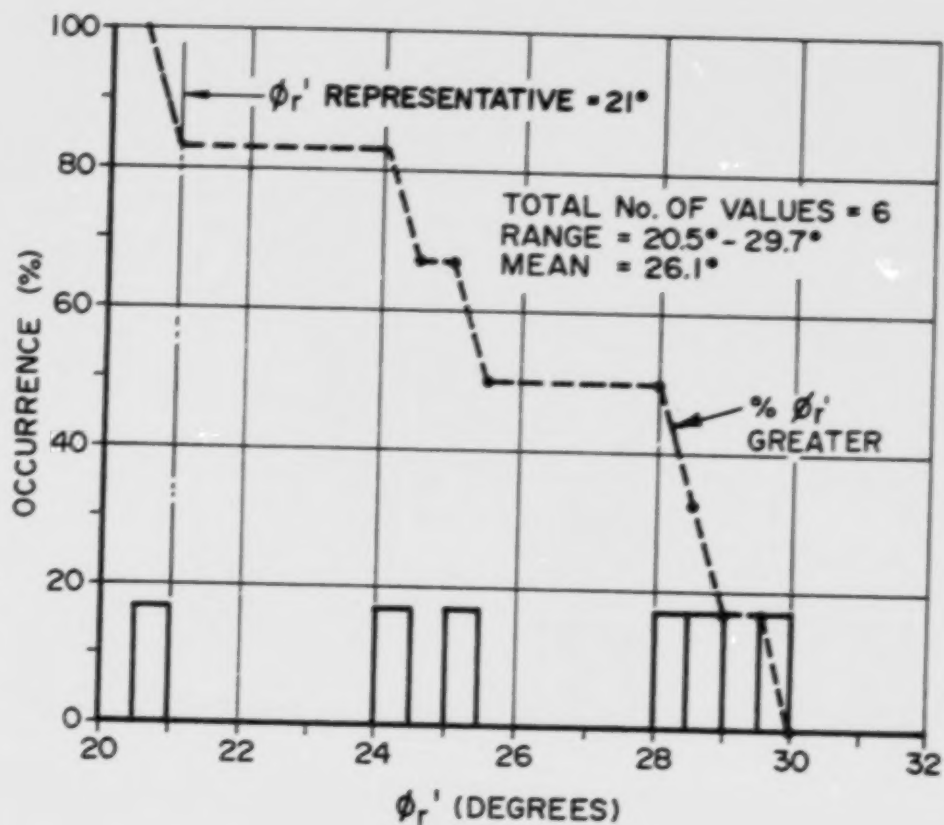
SHEAR STRENGTH - IN SITU
SEAM NO. V17

REFERENCE ELEVATION AT DAM AXIS = 1047.7 m

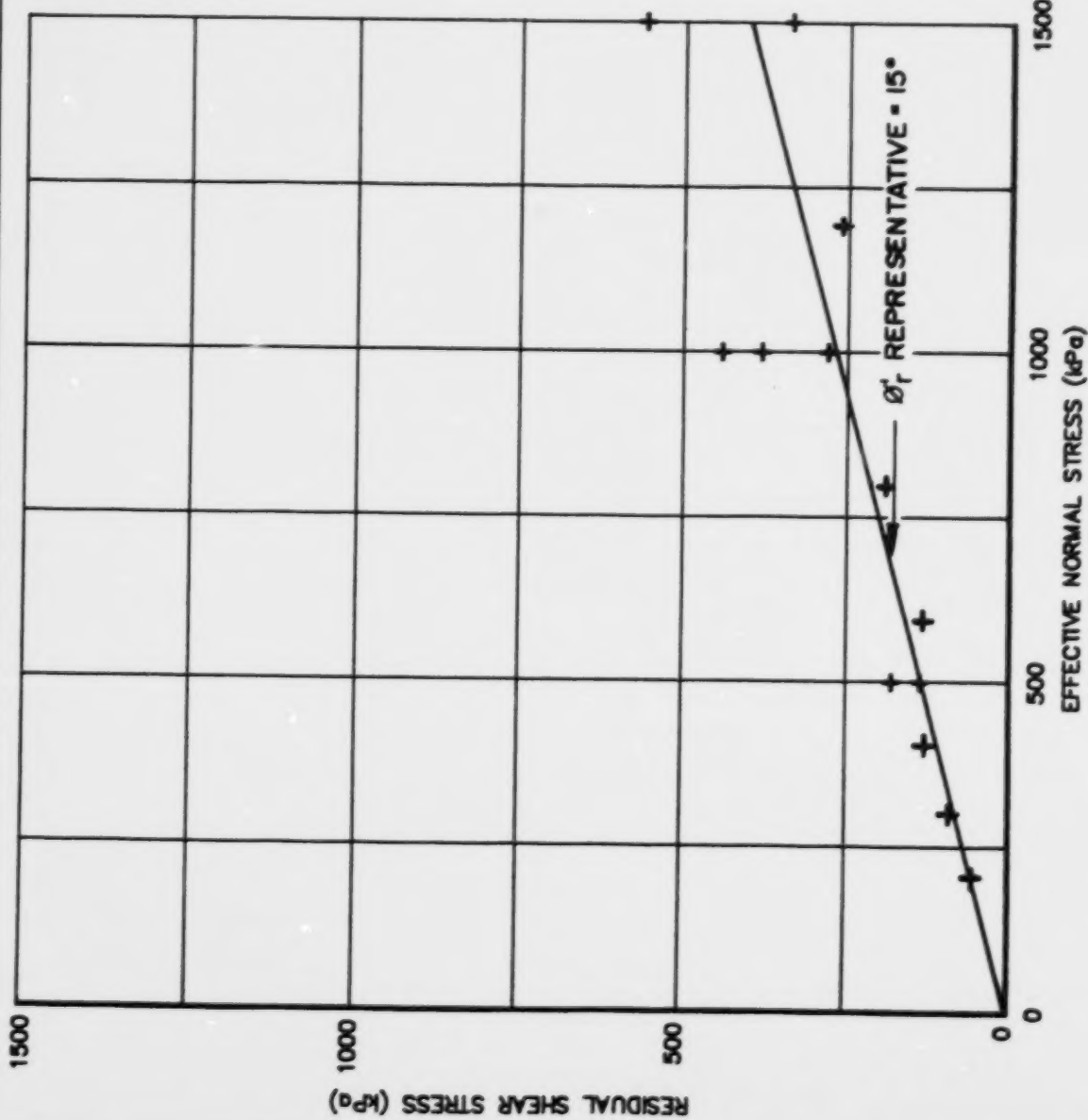


SHEAR STRENGTH - IN SITU
SEAM V17

PLATE B-126



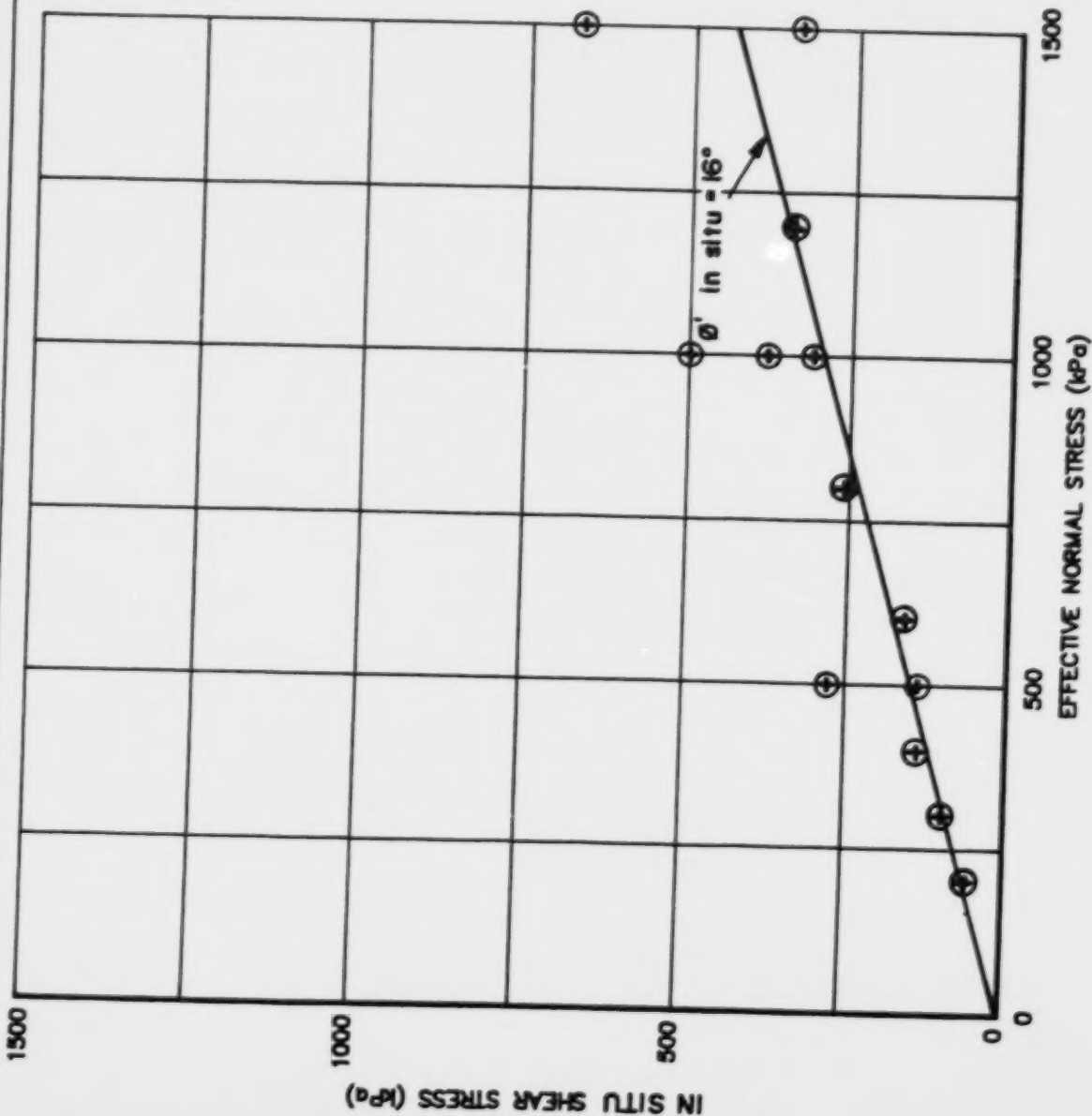
HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. 17
 REFERENCE ELEVATION AT DAM AXIS = 1047.7 m



Abt Associates
1015 W. 10th St.
Cheyenne, WY 82001
307.632.6000

SHEAR STRENGTH - RESIDUAL
BEAM VIB

REFERENCE ELEVATION AT DAM AXIS = 1049.4 m

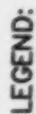


SHEAR STRENGTH - IN SITU
SEAM NO. V18
REFERENCE ELEVATION AT DAM AXIS = 1049.4 m



SHEAR STRENGTH - IN SITU
SEAM V18

PLATE B-129



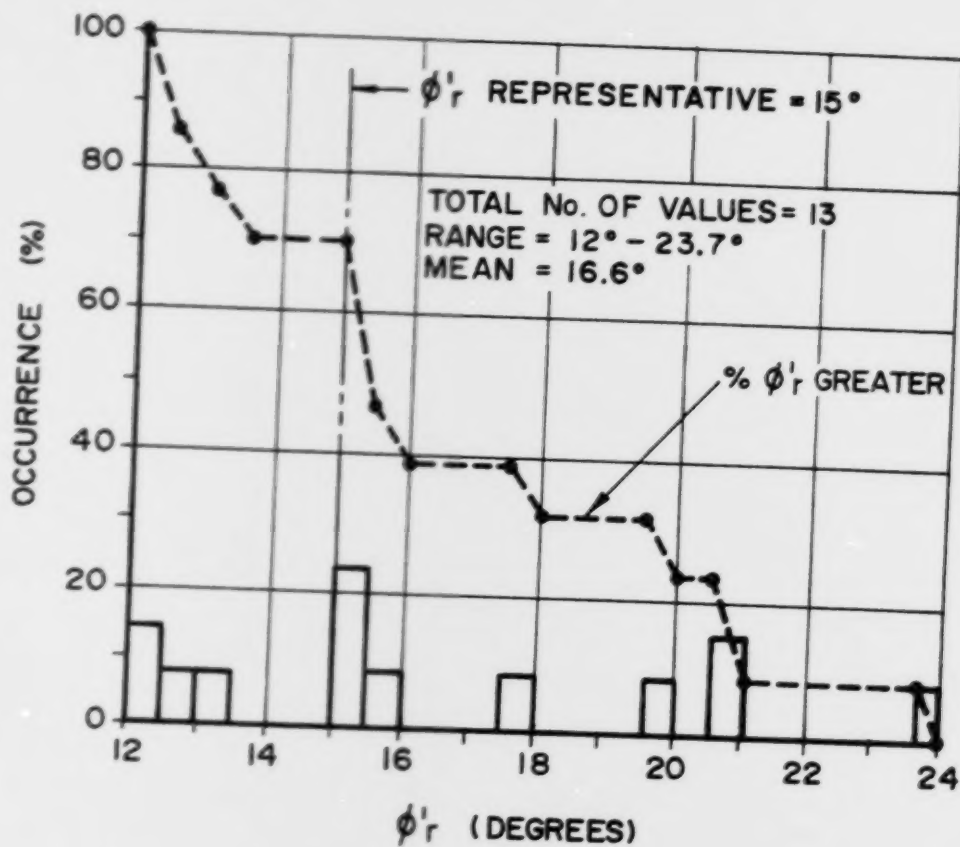
- | | | |
|---|---|---|
| ● | - | INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST |
| □ | - | SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST |
| + | - | SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH, 10 cm x 10 cm DIRECT SHEAR
TEST. |

IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO. V18
REFERENCE ELEVATION AT DAM AXIS = 1049.4 m

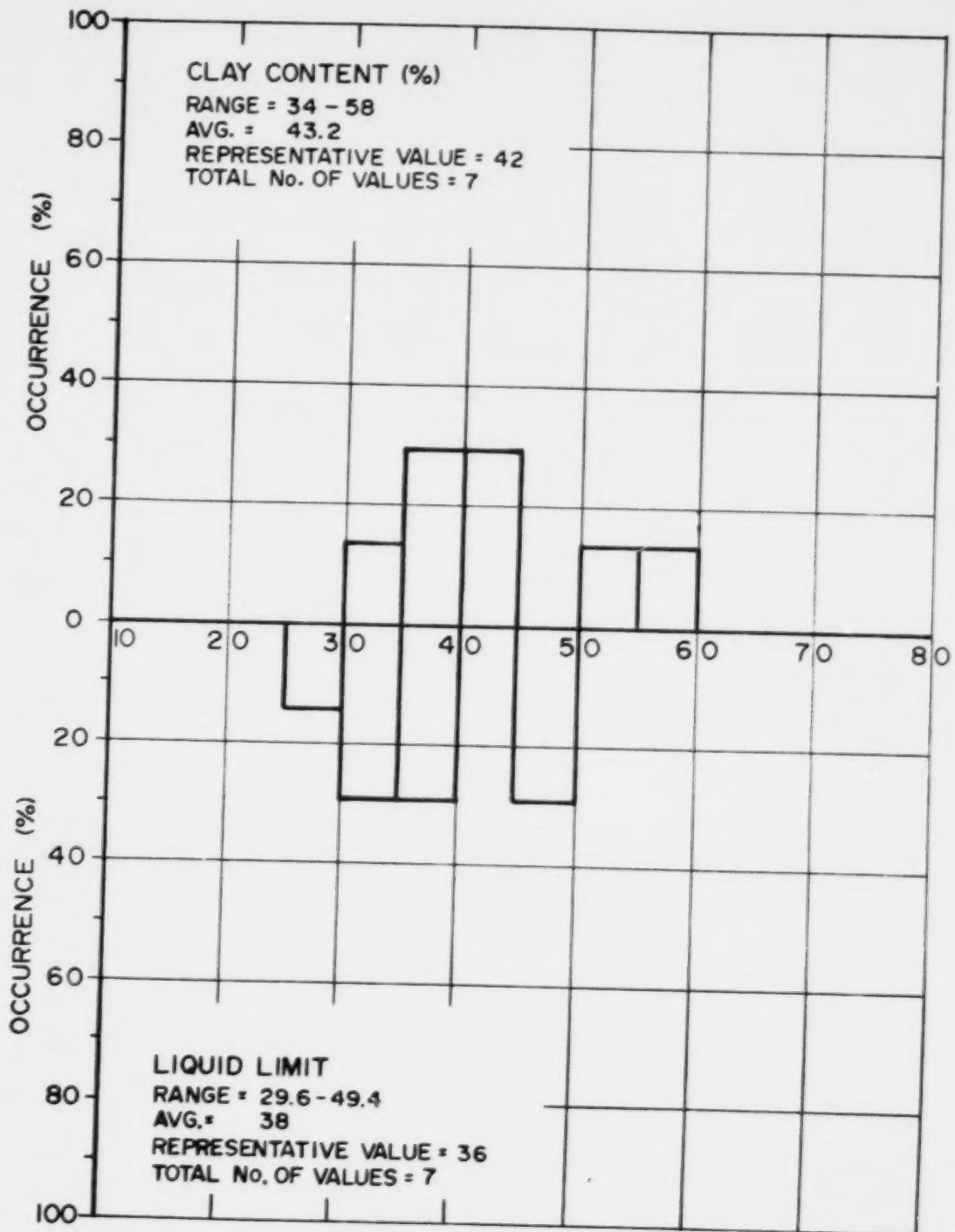


0' IN SITU vs 0';
SEAM VIO

PLATE B-130



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. V18
 REFERENCE ELEVATION AT DAM AXIS = 1049.4m

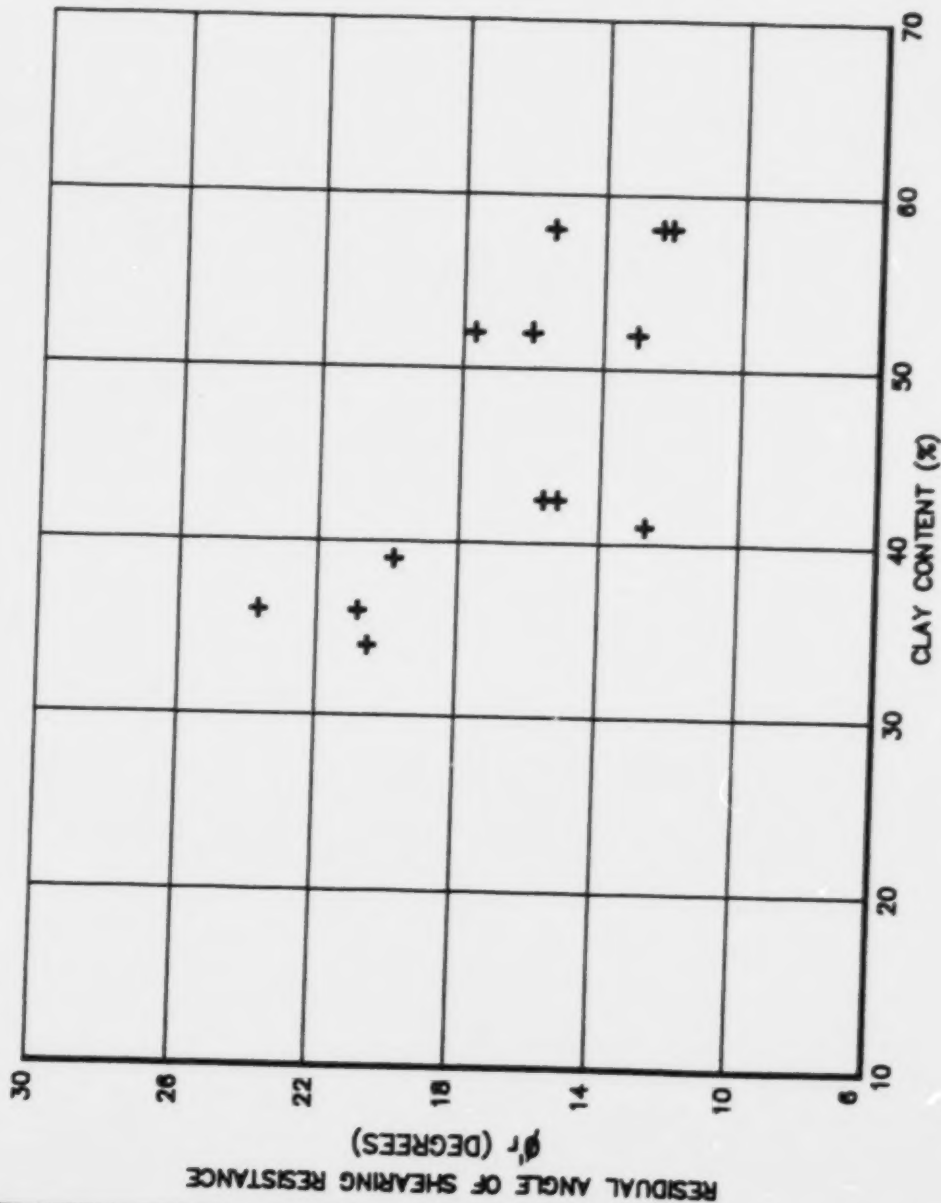


**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM No. VI8
 REFERENCE ELEVATION AT DAM AXIS = 1049.4 m**

ADCO  
 OLDMAN RIVER DAM

**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM VI8**

PLATE B-132



LEGEND:

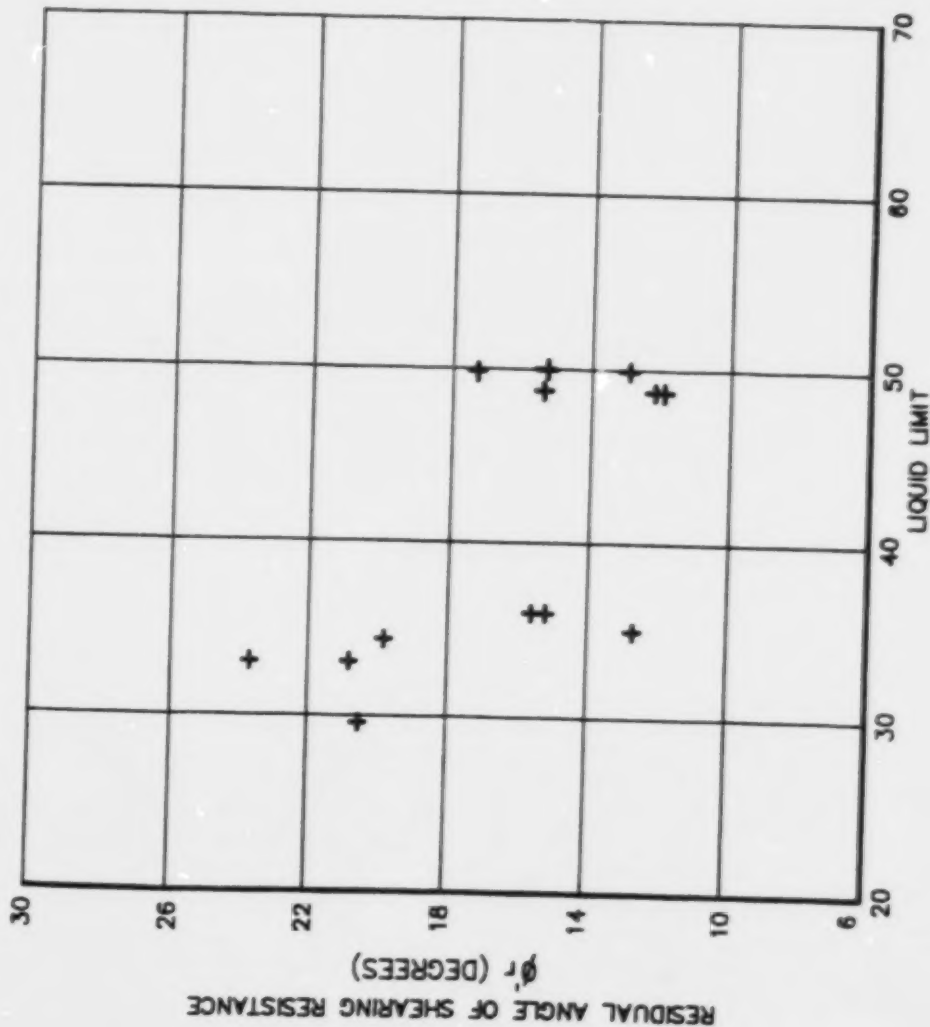
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
 - - 5 cm x 5 cm DIRECT SHEAR TEST
 - +
 - +
 - +
- SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM No. V18
REFERENCE ELEVATION AT DAM AXIS = 1049.4 m



9; VS CLAY CONTENT
SEAM V18

PLATE B-133



LEGEND:

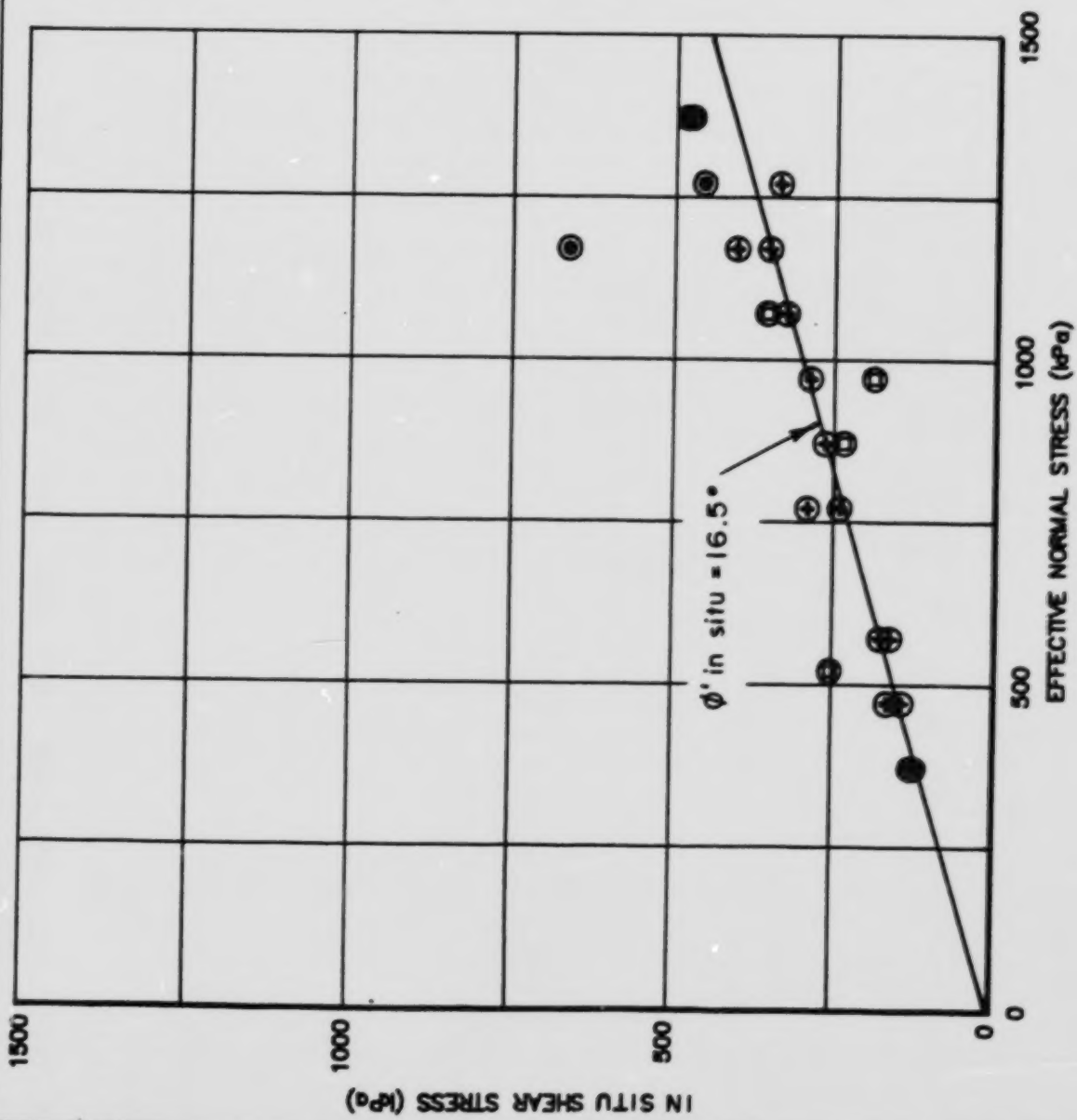
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- +

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM No. V18
REFERENCE ELEVATION AT DAM AXIS = 1049.4m



ϕ_r VS LIQUID LIMIT
SEAM V18

PLATE B-134



LEGEND:

- ⊕ - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

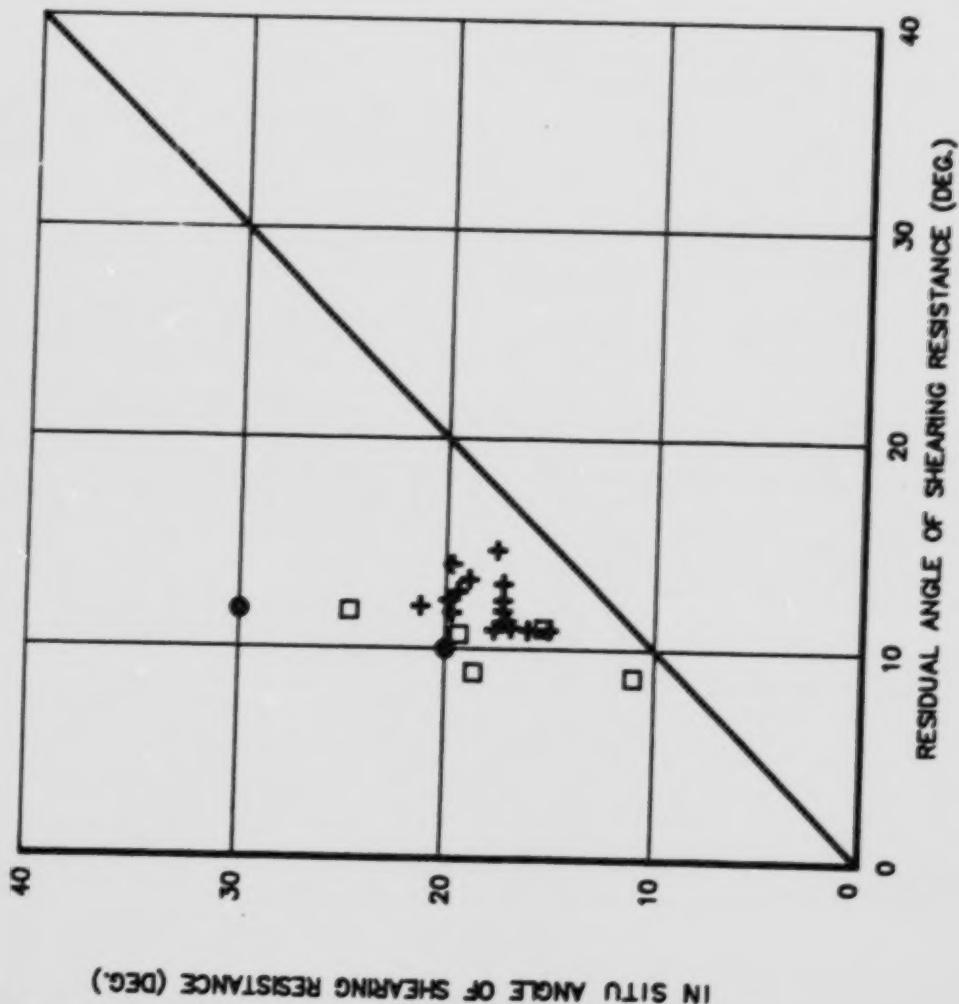


SHEAR STRENGTH - IN SITU
SEAM RI

REFERENCE ELEVATION AT SPILLWAY $\phi = 1068.2 \text{ m}$

LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH, 10 cm x 10 cm DIRECT SHEAR
TEST.

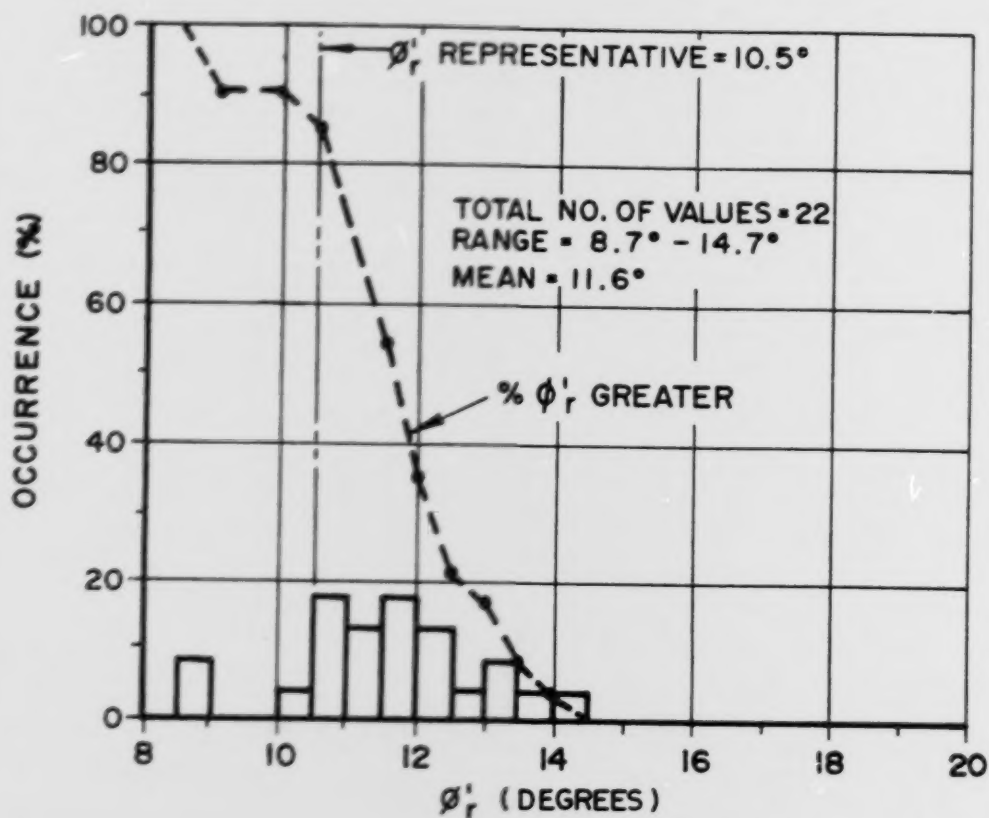


IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM No. R1
REFERENCE ELEVATION AT SPILLWAY $\phi = 1068.2$ m

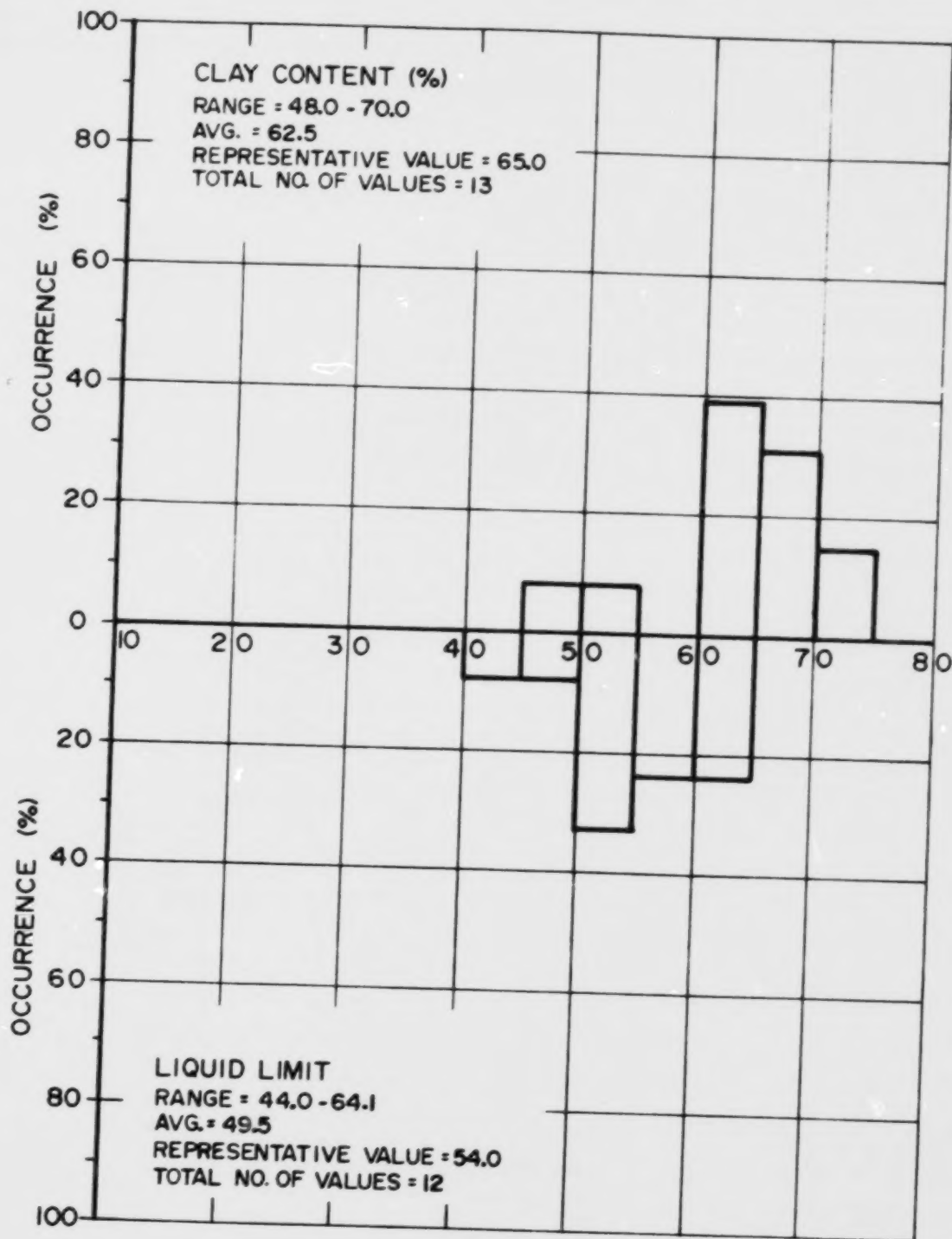


ϕ' IN SITU VS ϕ'
SEAM R1

PLATE B-137



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM NO. R1
 REFERENCE ELEVATION AT SPILLWAY $\zeta = 1068.2 \text{ m}$

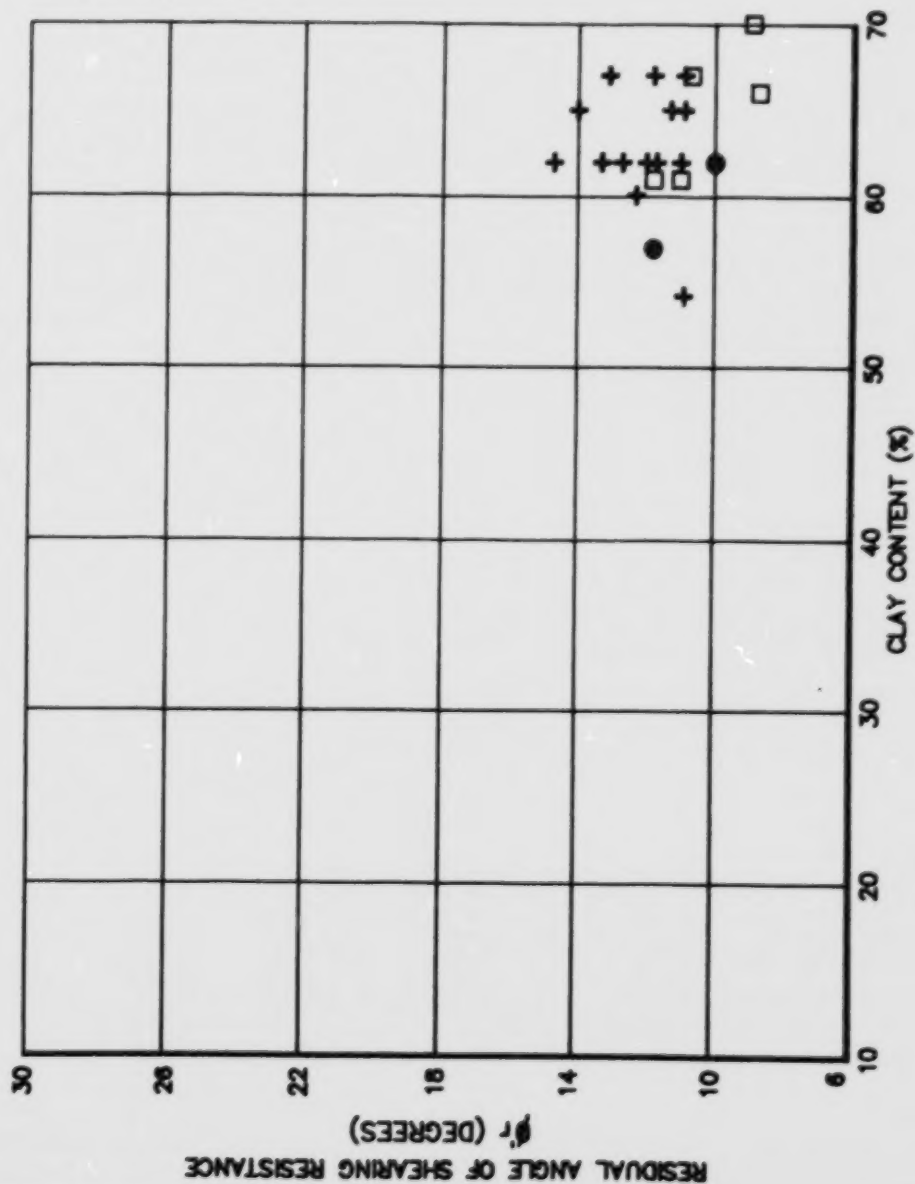


HISTOGRAM OF CLAY CONTENT AND LIQUID LIMIT

SEAM No. R1

REFERENCE ELEVATION AT SPILLWAY ζ = 1068.2 m

HISTOGRAM OF CLAY CONTENT AND LIQUID LIMIT SEAM R1
PLATE B-139

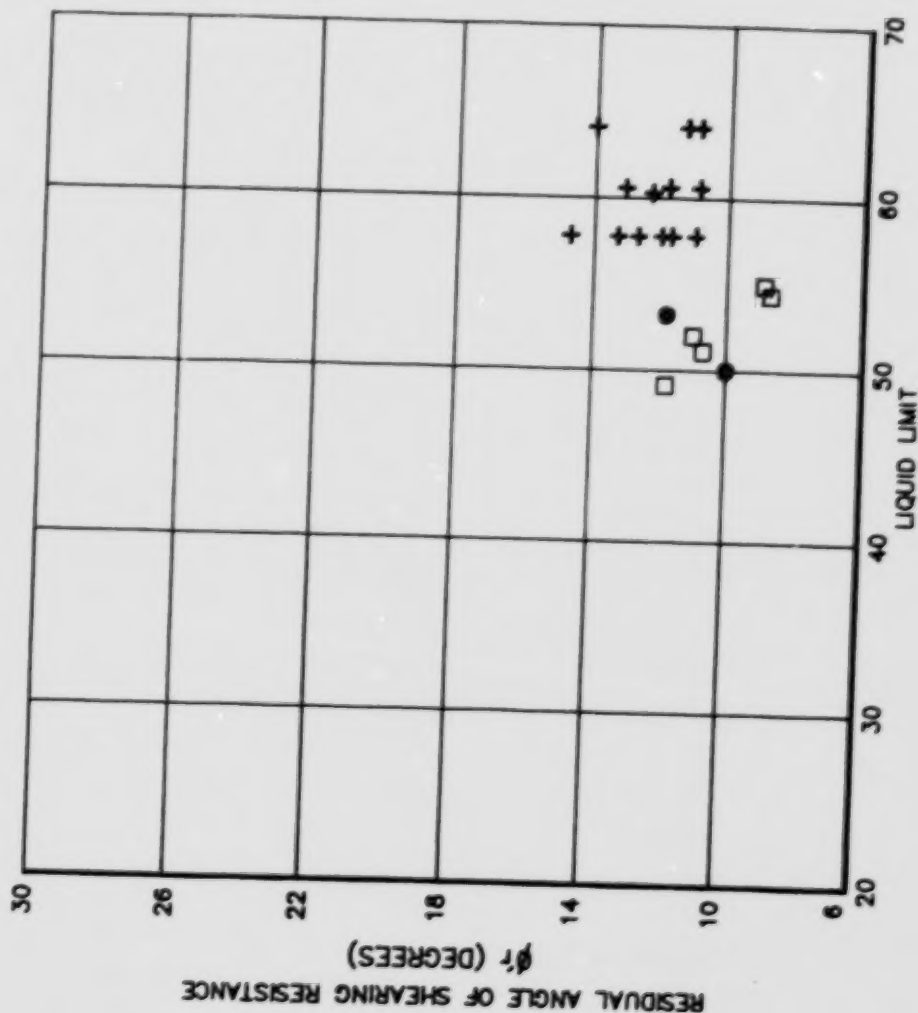


RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM NO R1
REFERENCE ELEVATION AT SPILLWAY $\bar{c} = 1068.2$ m



ϕ_r VS CLAY CONTENT
SEAM R1

PLATE B-140



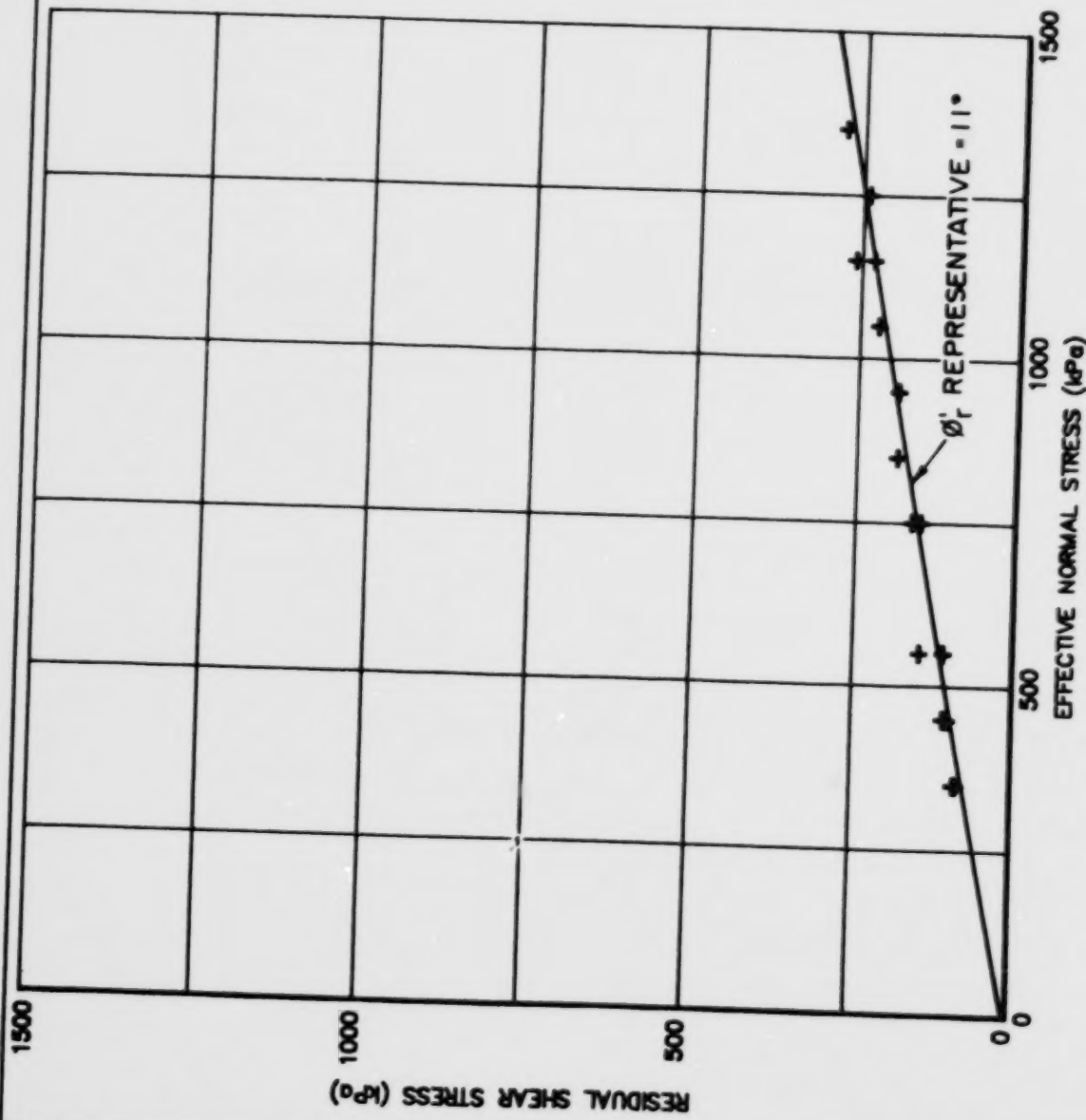
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- +



ϕ_r vs LIQUID LIMIT
SEAM R1

PLATE B-141



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
60.5	67.0
64.1	65.0
57.8	62.0
60.3	60.1
-	54.2
51.9	60.0
52.9	69.0
44.2	46.0
53.8	59.0
56.1	63.0
REPRESENTATIVE VALUES	
60.0	62.0

DEPARTMENT OF TRANSPORTATION

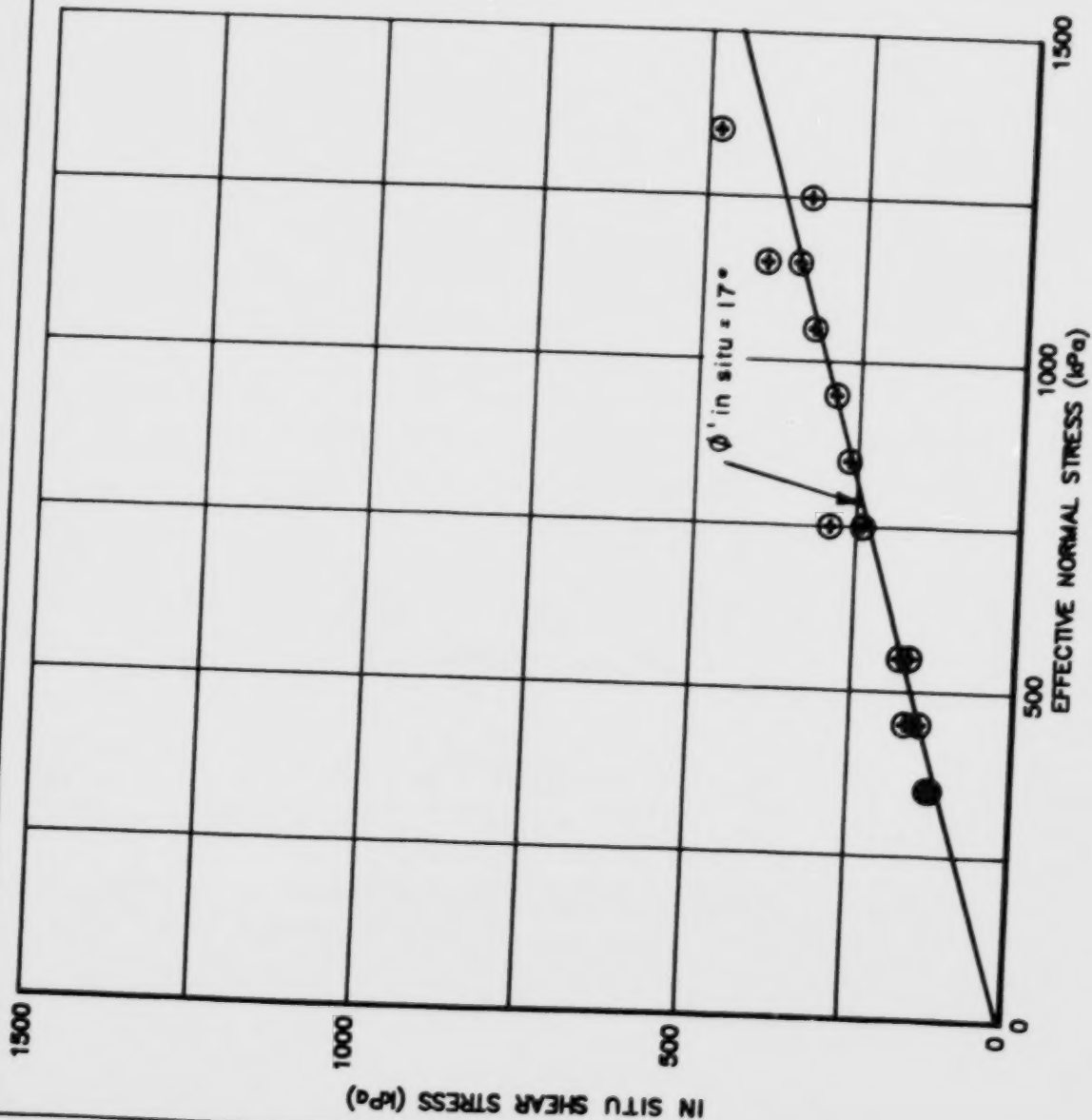
Highway Division

Bureau of Road Construction

SHEAR STRENGTH - RESIDUAL
LEFT BANK - ACCESS ROAD

PLATE B-142

SHEAR STRENGTH - RESIDUAL
LEFT BANK ACCESS ROAD
CORRESPONDING TO SEAM NO. R1
REFERENCE ELEVATION AT SPILLWAY $\phi = 1068.2$ m



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



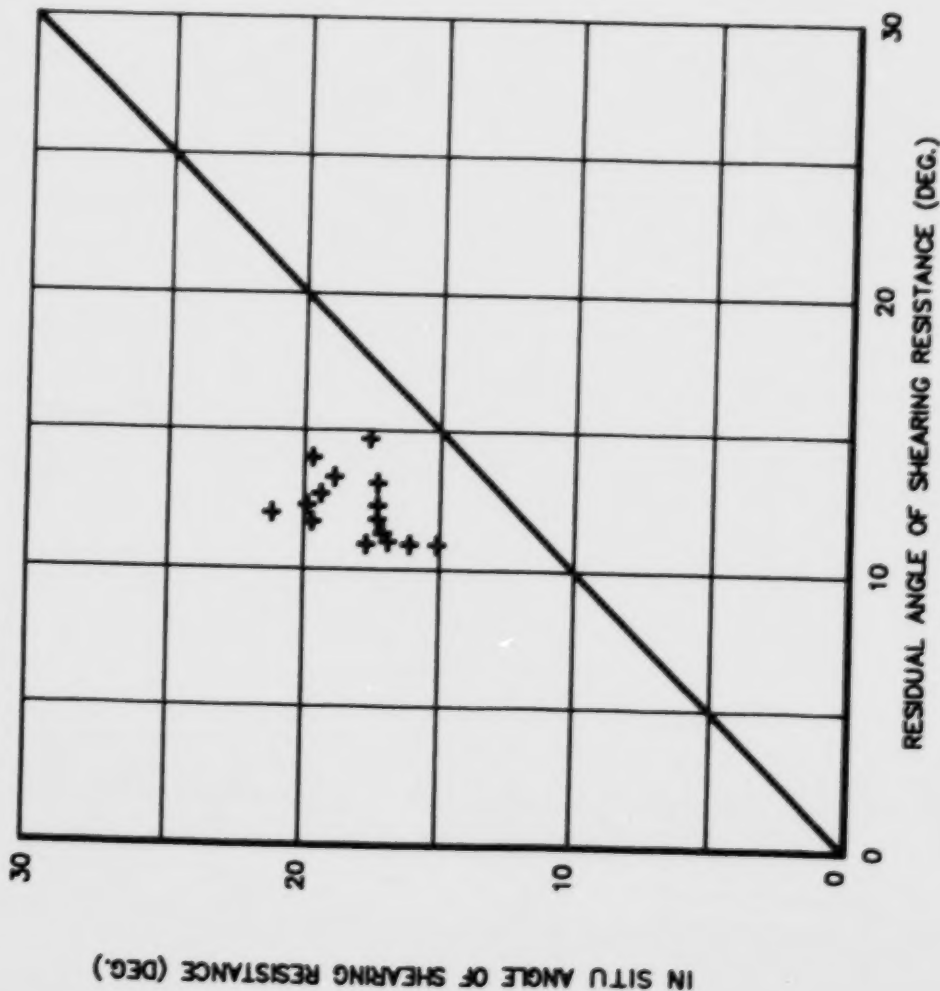
SHEAR STRENGTH - IN SITU
LEFT BANK ACCESS ROAD

PLATE B-143

SHEAR STRENGTH - IN SITU
LEFT BANK ACCESS ROAD
CORRESPONDING TO SEAM NO. R1
REFERENCE ELEVATION AT SPILLWAY $\phi = 1068.2$ m

LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH, 10 cm x 10 cm DIRECT SHEAR
TEST.

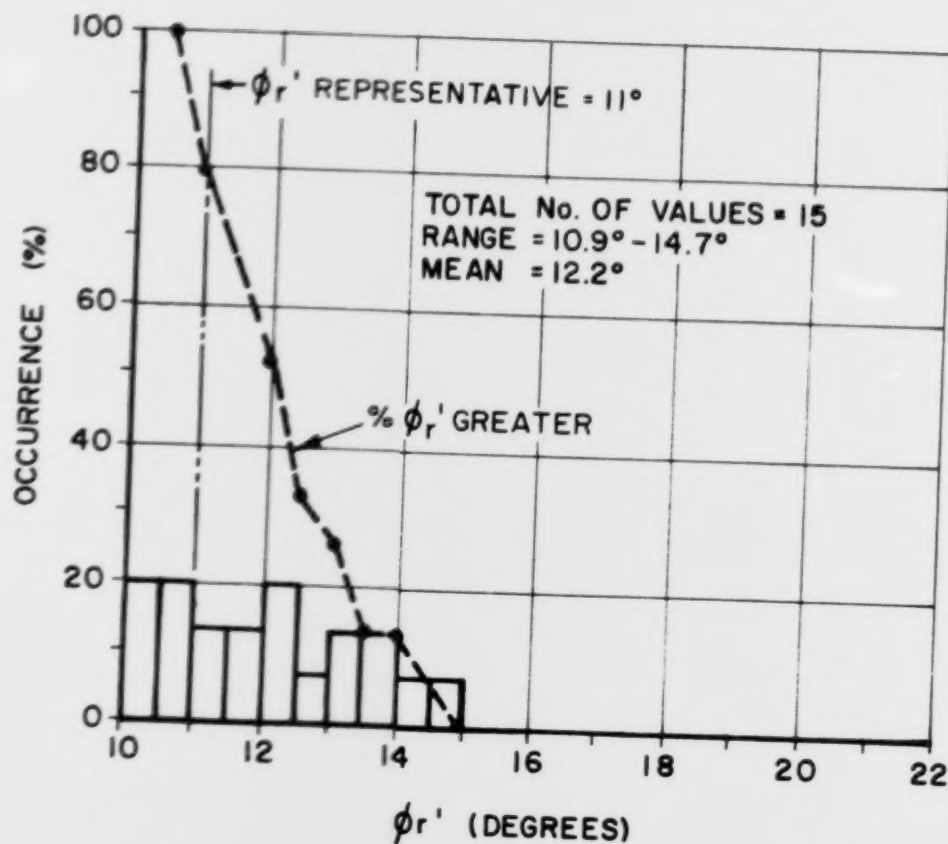


IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
LEFT BANK ACCESS ROAD
CORRESPONDING TO SEAM NO. R1
REFERENCE ELEVATION AT SPILLWAY $\phi = 1068.2$ m

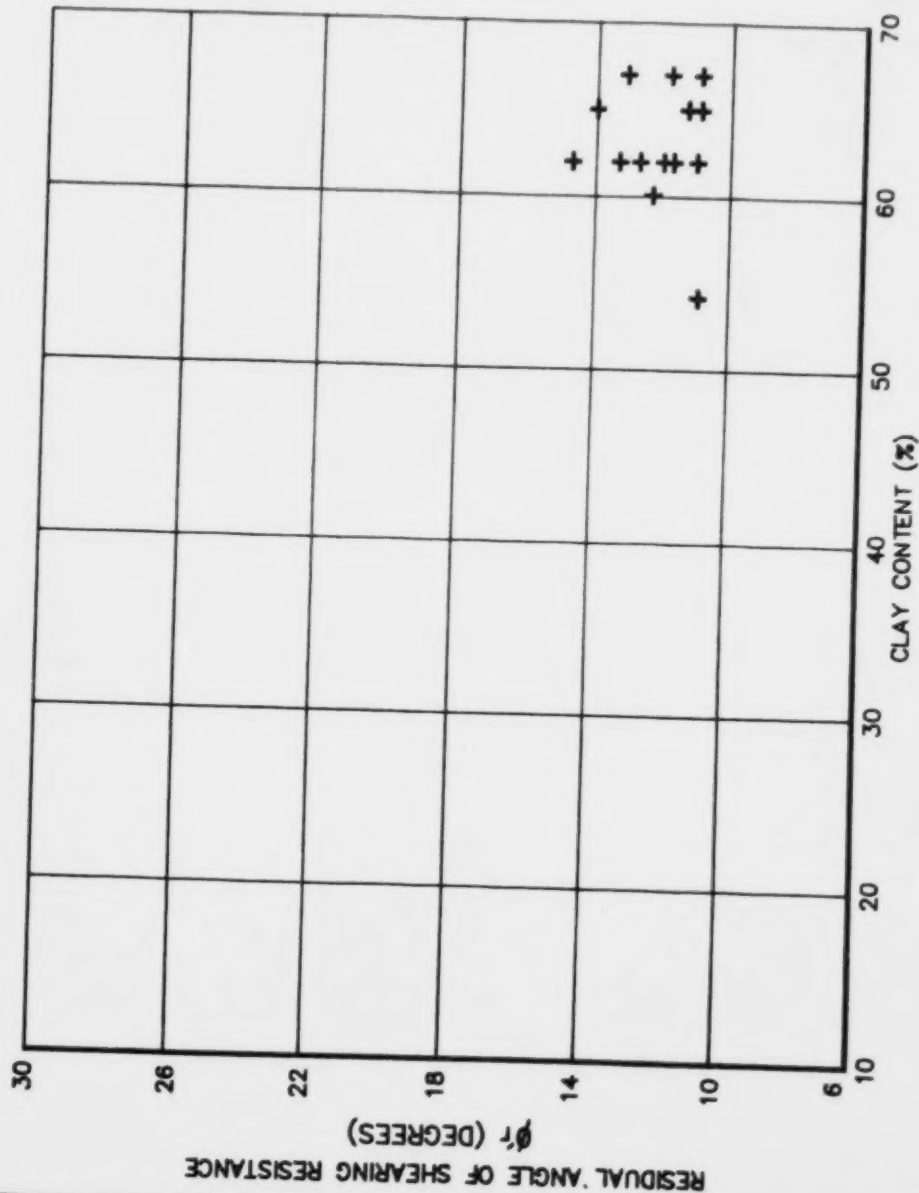


φ' IN SITU VS φ;
LEFT BANK - ACCESS ROAD

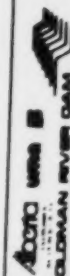
PLATE B-144



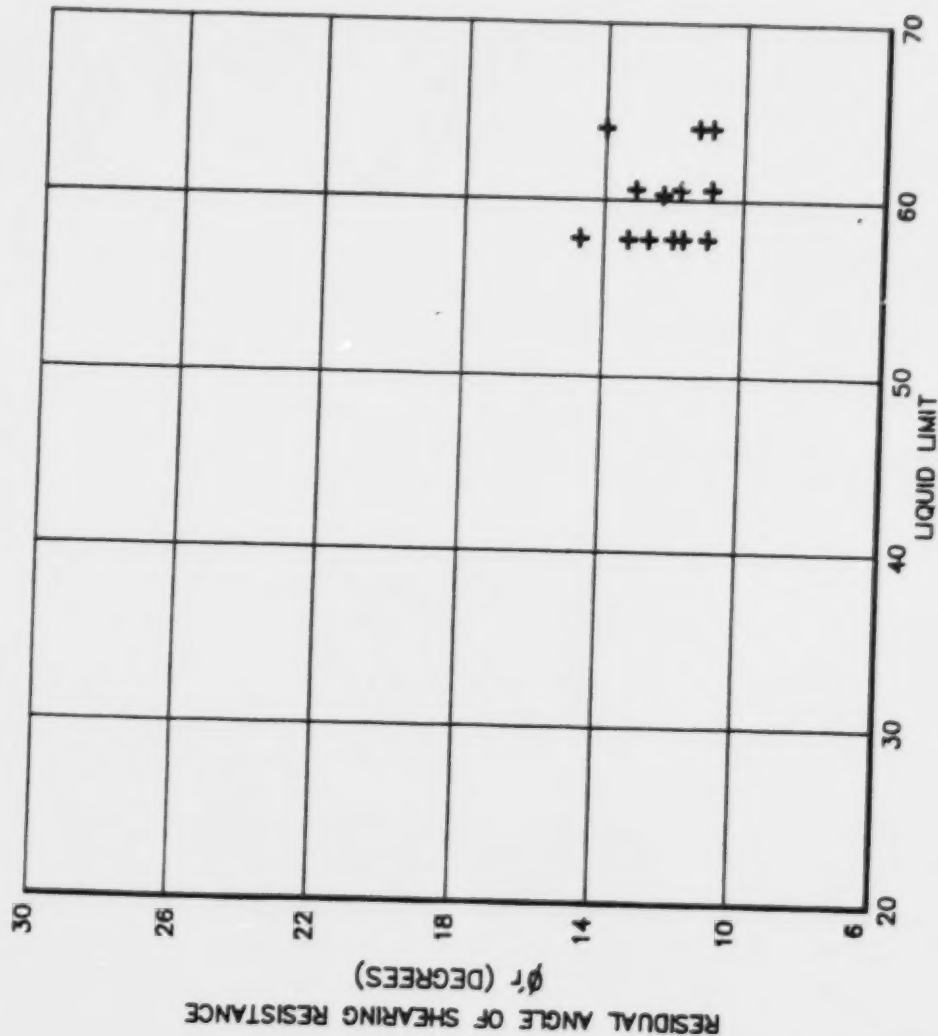
HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 LEFT BANK-ACCESS ROAD
 CORRESPONDING TO SEAM NO. R1
 REFERENCE ELEVATION AT SPILLWAY $\zeta = 1068.2\text{m}$



RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
 LEFT BANK ACCESS ROAD
 CORRESPONDING TO SEAM NO. R1
 REFERENCE ELEVATION AT SPILLWAY $\phi = 1068.2$ m



ϕ_r VS CLAY CONTENT
 LEFT BANK ACCESS ROAD



LEGEND:

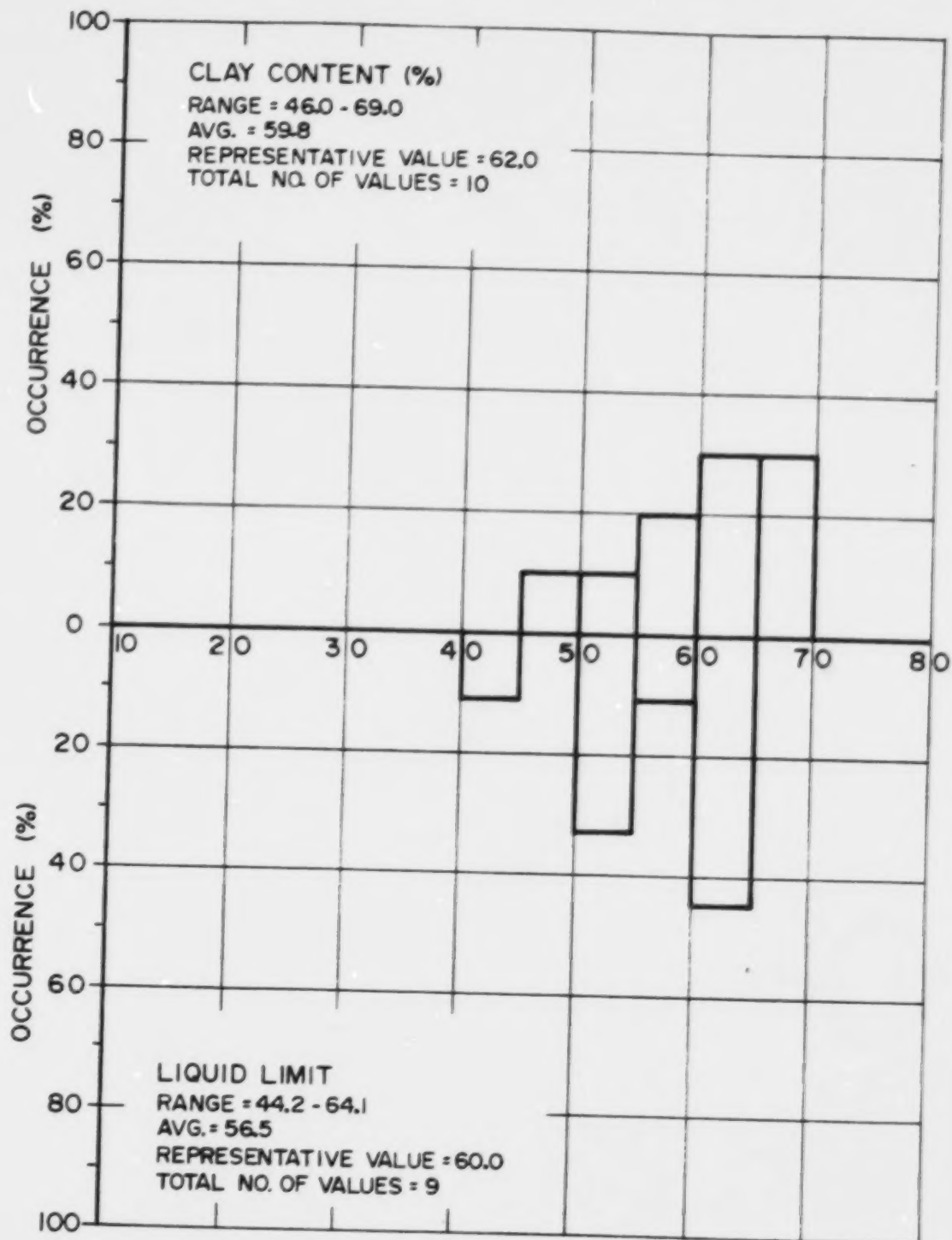
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs LIQUID LIMIT
LEFT BANK ACCESS ROAD

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
LEFT BANK ACCESS ROAD
CORRESPONDING TO SEAM NO. R1
REFERENCE ELEVATION AT SPILLWAY $\phi = 1068.2$ m

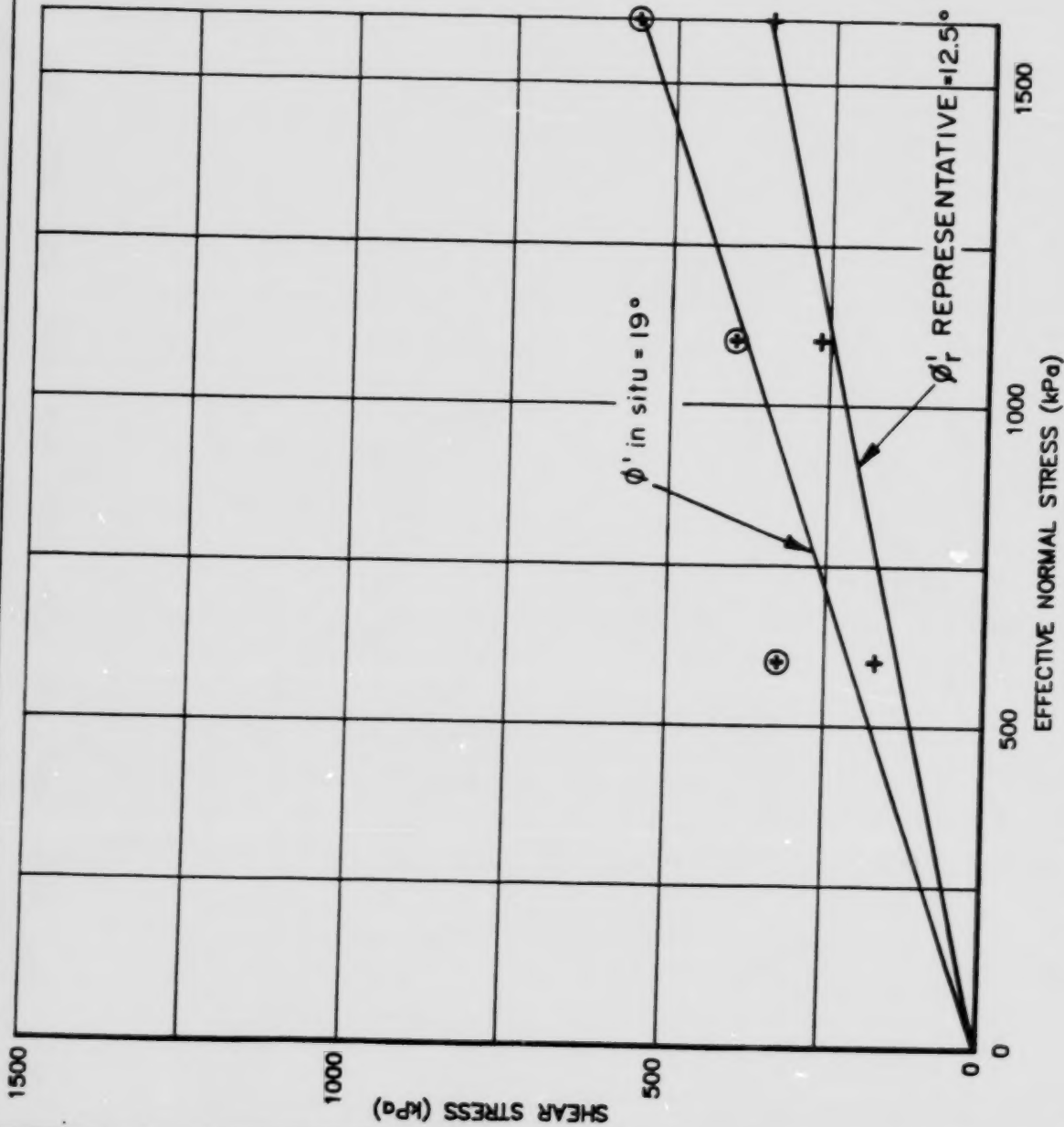
PLATE B-147



HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 LEFT BANK ACCESS ROAD
 CORRESPONDING TO SEAM NO. R1
 REFERENCE ELEVATION AT SPILLWAY $\zeta = 1068.2\text{m}$

HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 LEFT BANK ACCESS ROAD

PLATE B-148



LEGEND:

RESIDUAL

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- +
- - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

PEAK

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
41.0	50.0
44.4	41.0
31.0	31.0
51.0	52.5
43.0	49.0
REPRESENTATIVE VALUES	
43.0	49.0

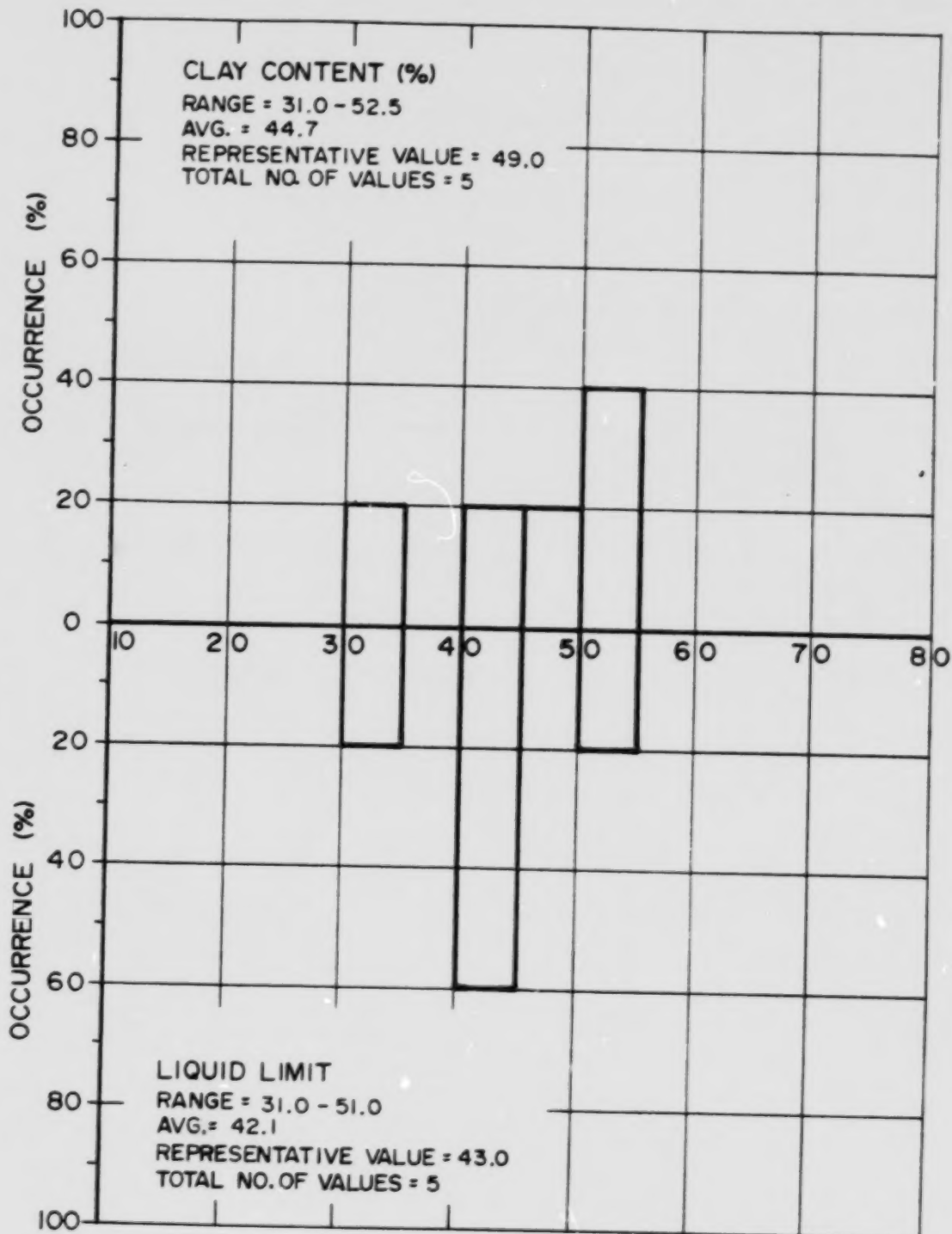
500 1000 1500

SHEAR STRENGTH - IN SITU AND RESIDUAL
SEAM NO. R6
REFERENCE ELEVATION AT SPILLWAY $\phi = 1084.5 \text{ m}$



SHEAR STRENGTH
SEAM R6

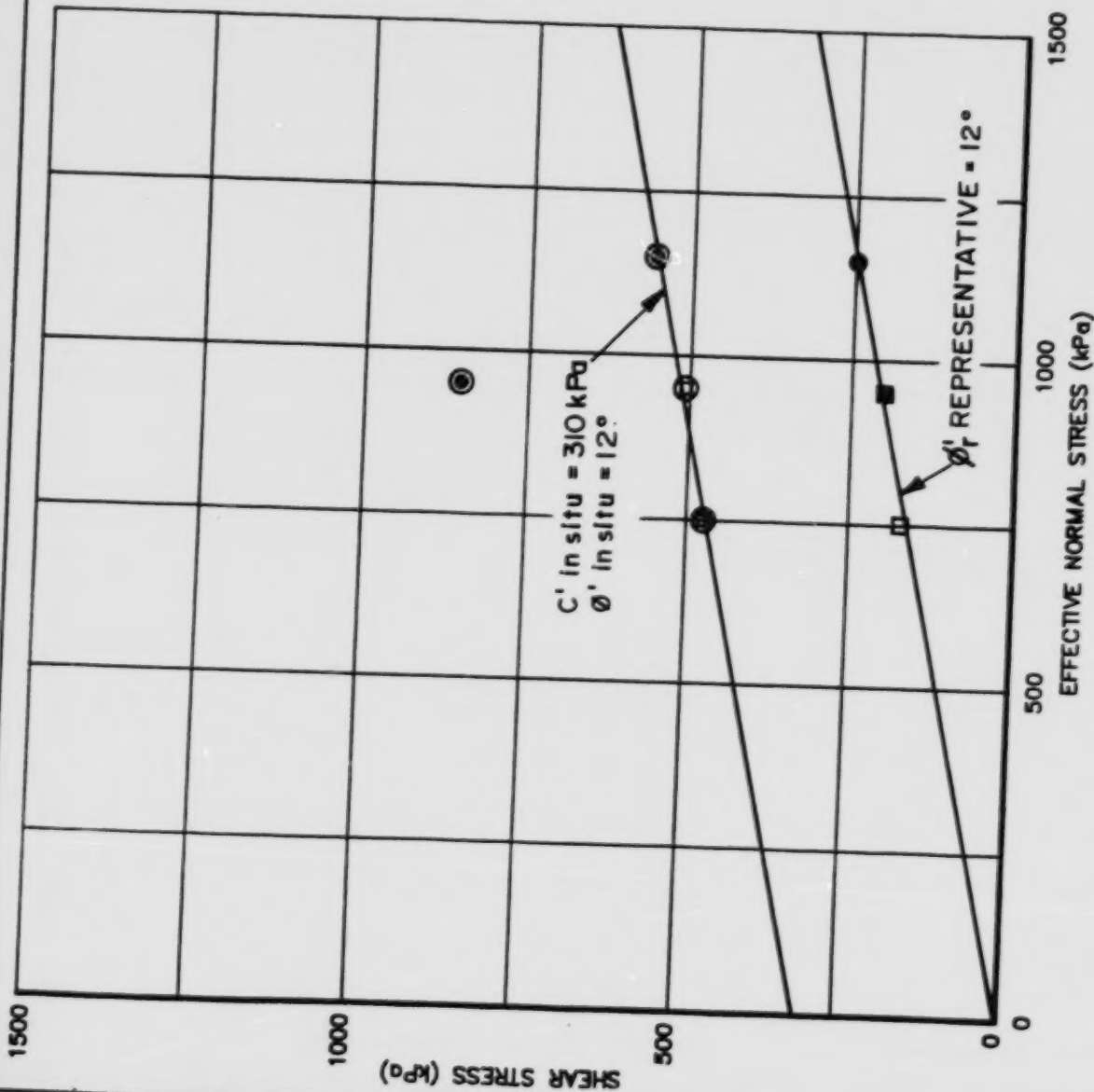
PLATE B-I49



HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM NO. R6

REFERENCE ELEVATION AT SPILLWAY $\zeta = 1084.5\text{m}$

 
HISTOGRAM OF CLAY CONTENT AND LIQUID LIMIT SEAM R6
PLATE B-150



SHEAR STRENGTH - IN SITU AND RESIDUAL
SEAM NO. R7
REFERENCE ELEVATION AT SPILLWAY $\phi = 1086.5 \text{ m}$

LEGEND:

RESIDUAL

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

PEAK

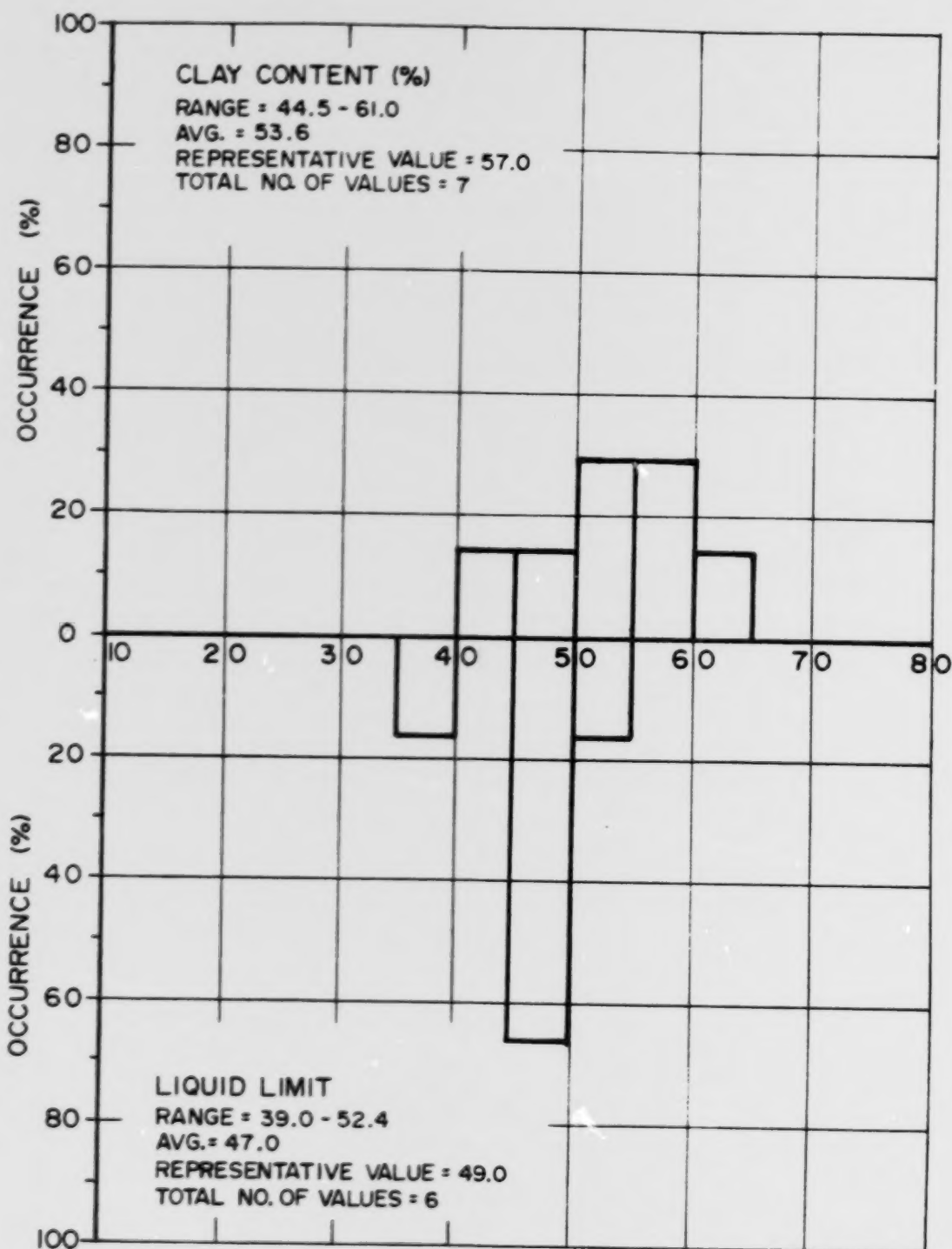
- ⊙ - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊗ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
39.0	44.5
47.5	53.0
47.9	61.0
47.0	59.0
-	48.0
52.4	-
-	58.0
48.1	52.0
REPRESENTATIVE VALUES	
49.0	57.0



SHEAR STRENGTH
SEAM R7

PLATE B-151

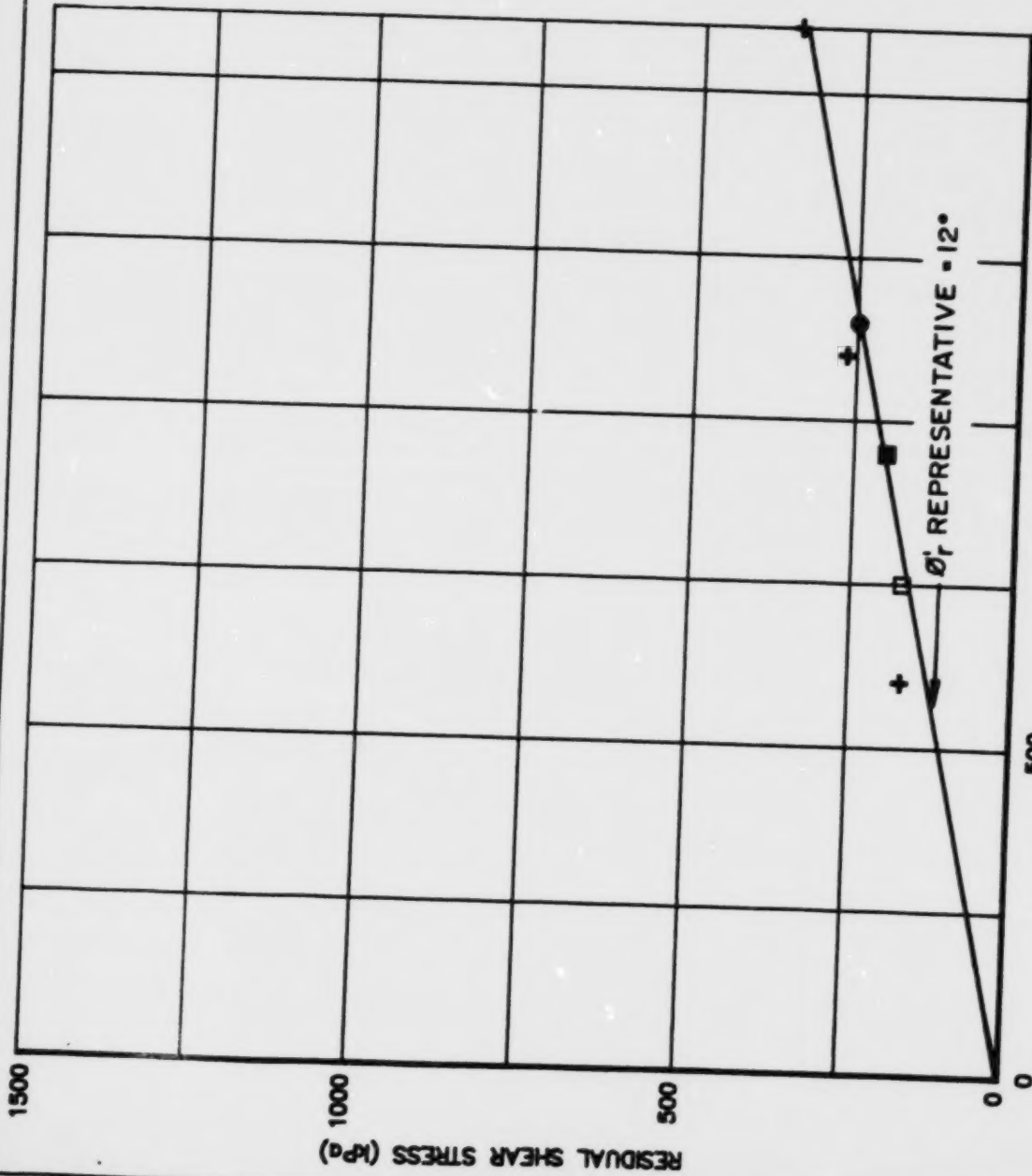


HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM NO. R7
 REFERENCE ELEVATION AT SPILLWAY $C_L = 1086.5\text{m}$

ADCO  
 CLEMAN RIVER DAM

HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM R7

PLATE B-152



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- +

SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
39.0	44.5
47.5	53.0
47.9	61.0
47.0	59.0
-	48.0
52.4	-
-	58.0
48.1	52.0
41.0	50.0
44.4	41.0
31.0	31.0
51.0	52.5
43.0	48.0
REPRESENTATIVE VALUES	
48.0	55.0

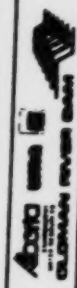
1500

500

EFFECTIVE NORMAL STRESS (kPa)

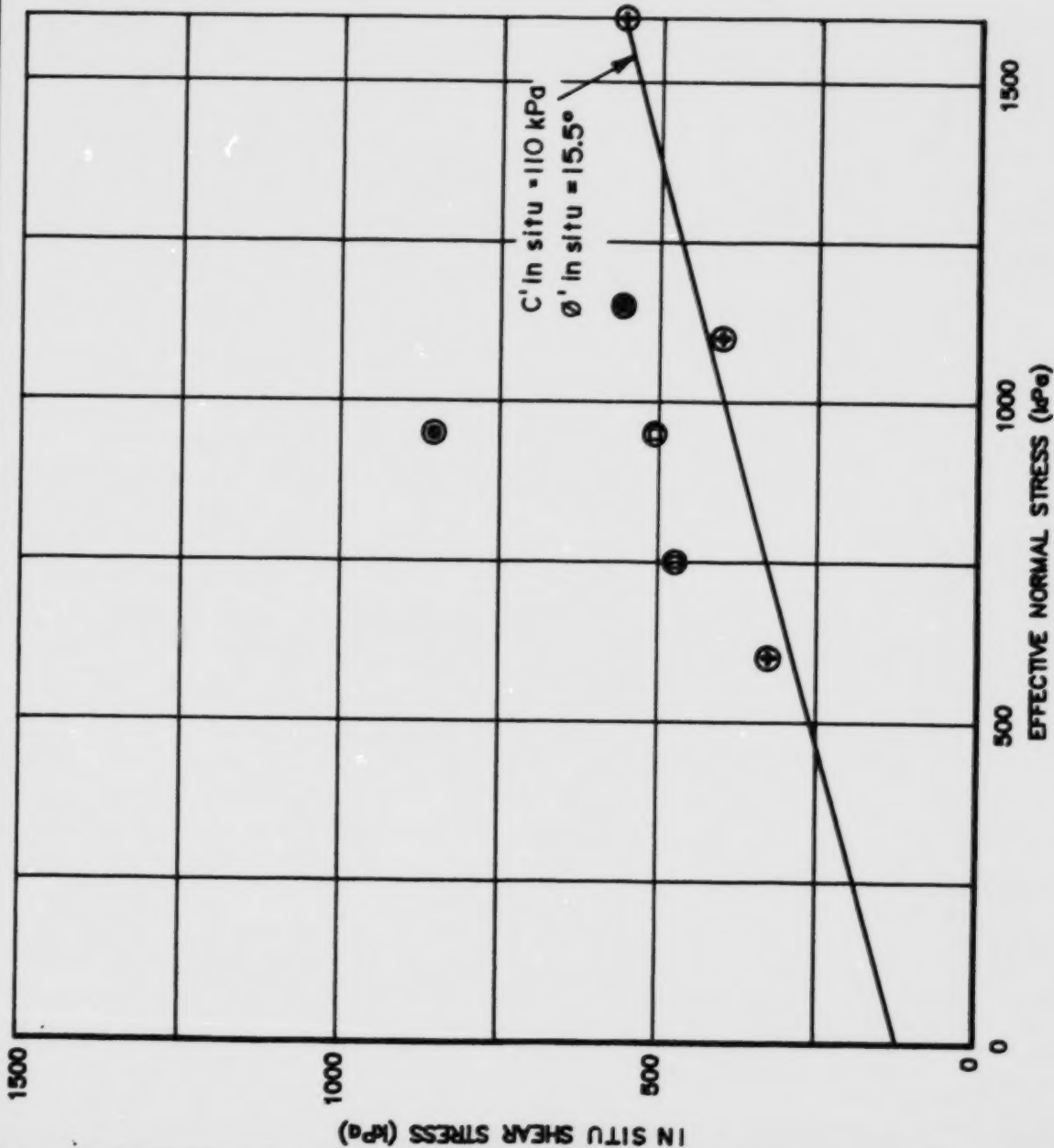
SHEAR STRENGTH - RESIDUAL SEAMS NO. R6 & R7

REFERENCE ELEVATION AT SPILLWAY ϕ = 1084.5 - 1086.5 m



SHEAR STRENGTH-RESIDUAL SEAMS R6 AND R7

PLATE B-153

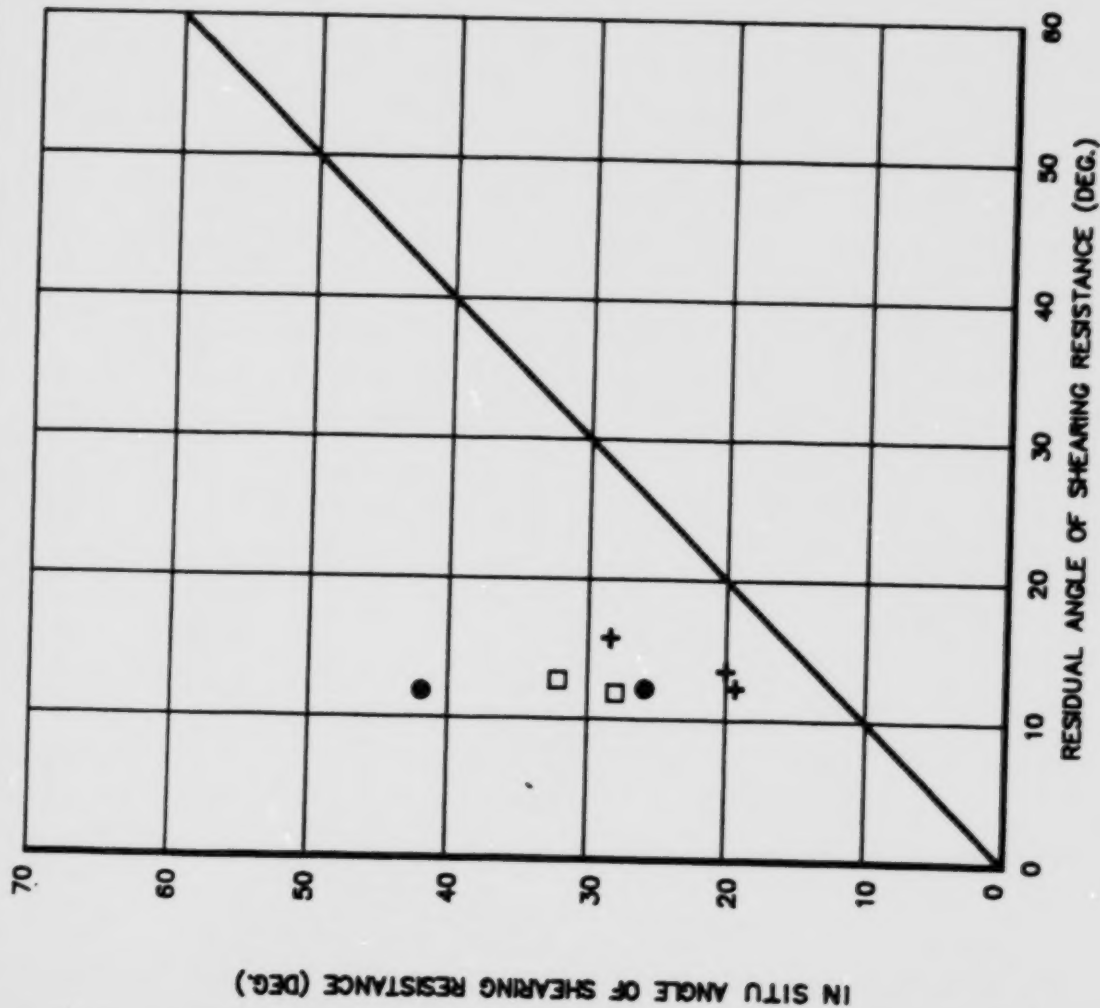


SHEAR STRENGTH - IN SITU
 SEAMS NO. R6 & R7
 REFERENCE ELEVATION AT SPILLWAY $\zeta = 1084.5 - 1086.5 \text{ m}$



SHEAR STRENGTH - IN SITU
 SEAMS R6 AND R7

PLATE B-154



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

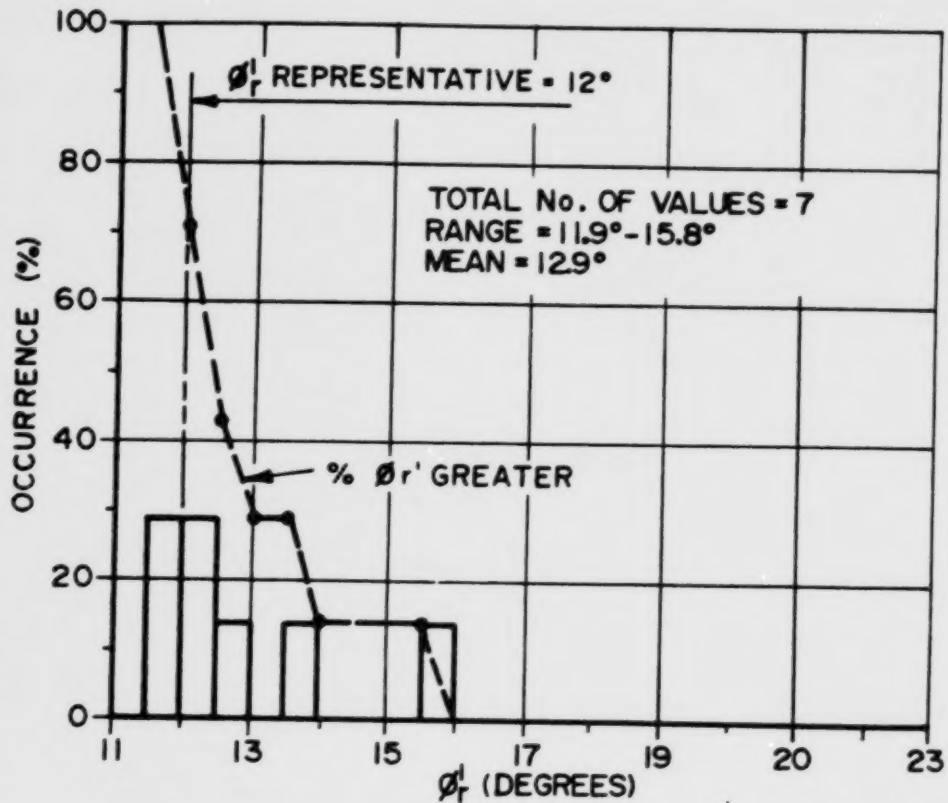


ϕ' in situ vs ϕ_r

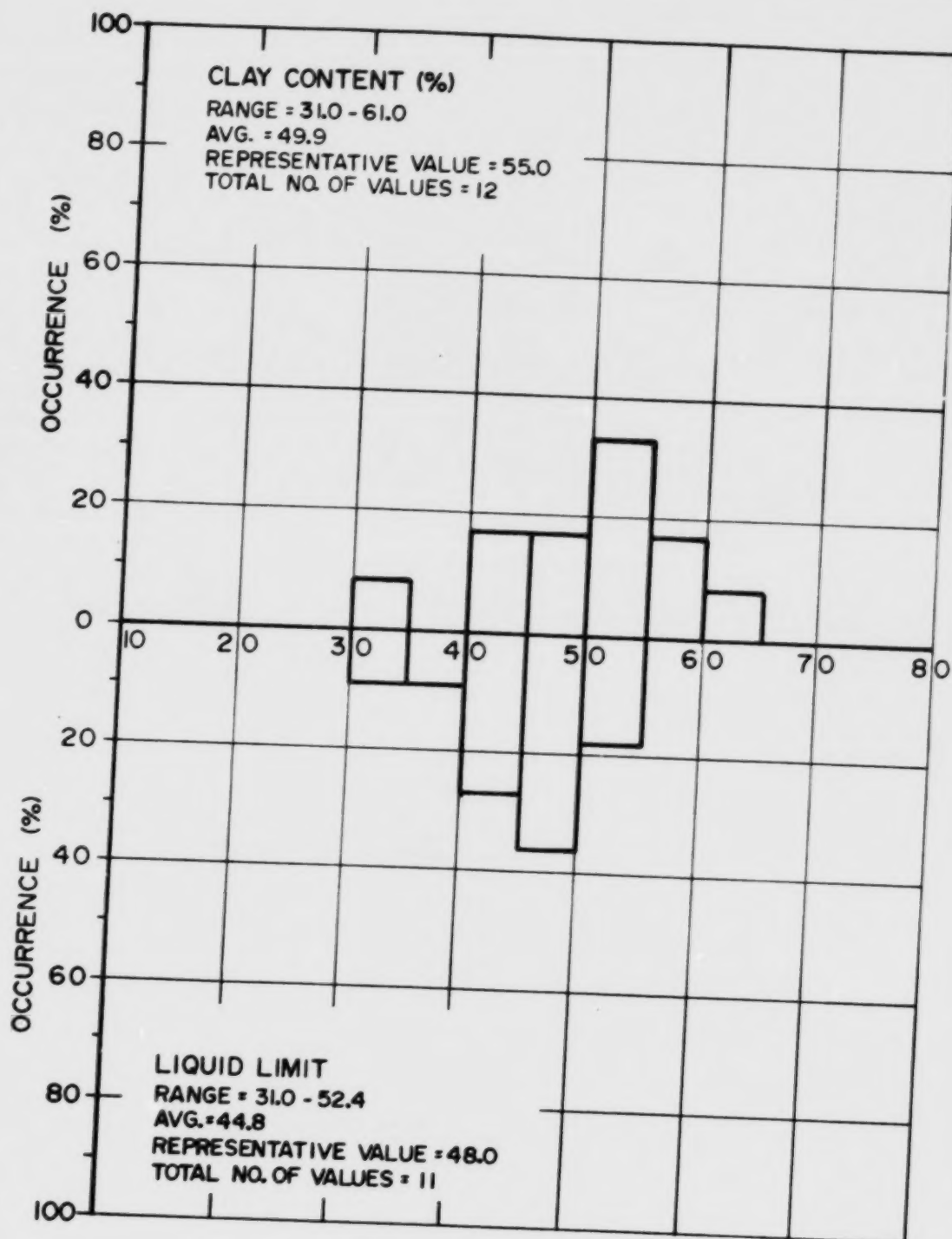
SEAMS R6 AND R7

IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAMS NO. R6 & R7
REFERENCE ELEVATION AT SPILLWAY $\phi = 1184.5 - 1086.5$ m

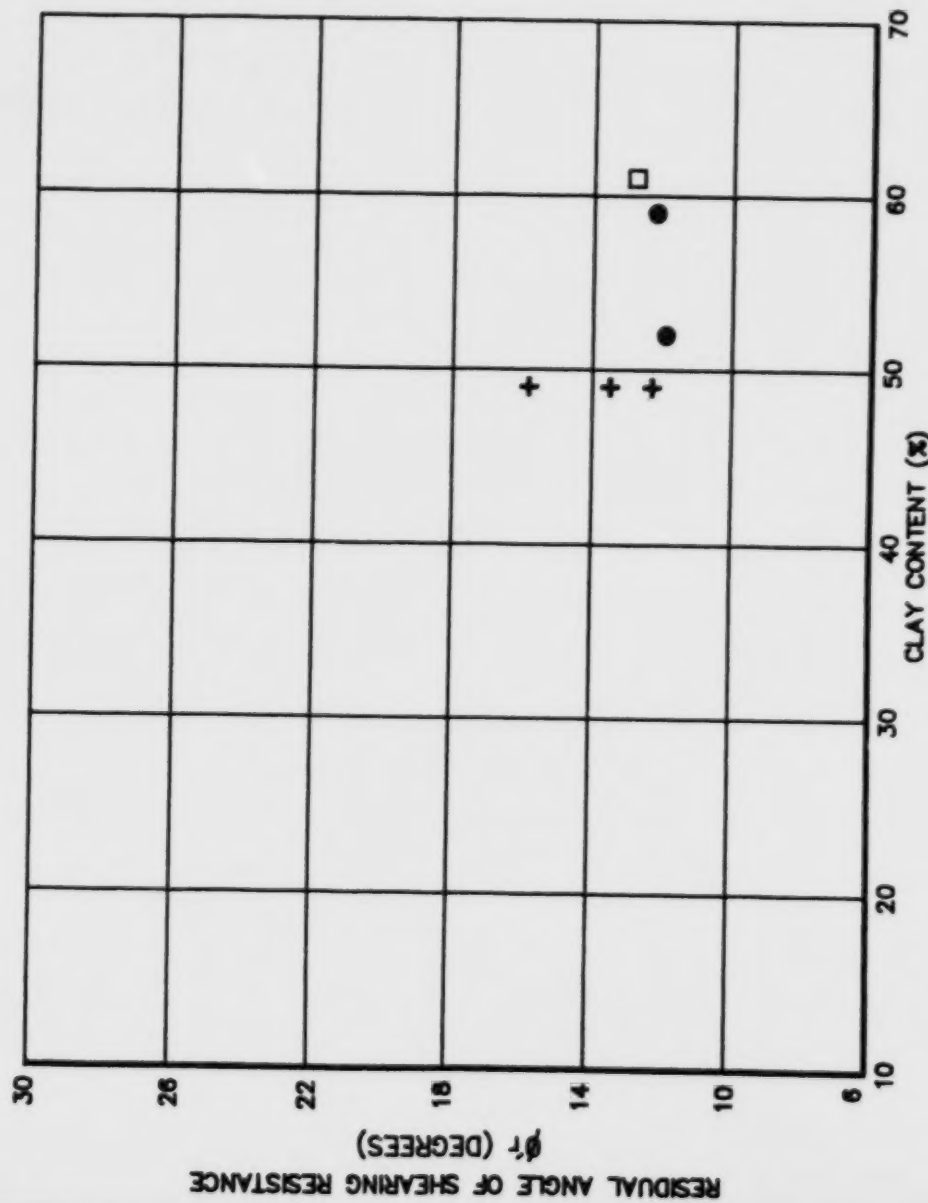
PLATE B-155



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
SEAMS NO. R6 & R7
REFERENCE ELEVATION AT SPILLWAY ζ = 1084.5m TO 1086.5 m



**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAMS NO. R6 AND R7
 REFERENCE ELEVATION
 AT SPILLWAY $\bar{C}$ = 1084.5m TO 1086.5 m**



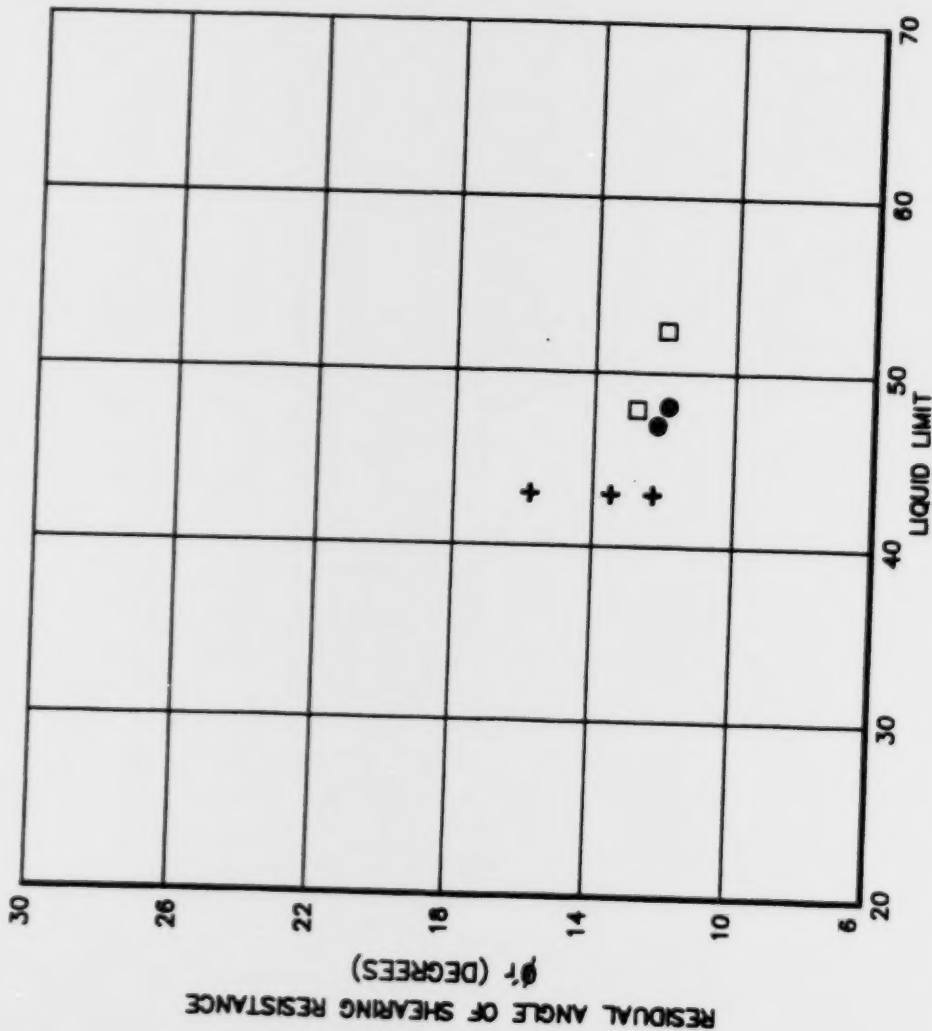
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAMS NO. R6 AND R7

REFERENCE ELEVATION AT SPILLWAY $\phi = 1084.5 - 1086.5$ m



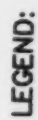
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs LIQUID LIMIT
 SEAMS R6 AND R7

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
 SEAMS NO. R6 AND R7
 REFERENCE ELEVATION AT SPILLWAY $\phi_c = 1084.5 - 1086.5m$



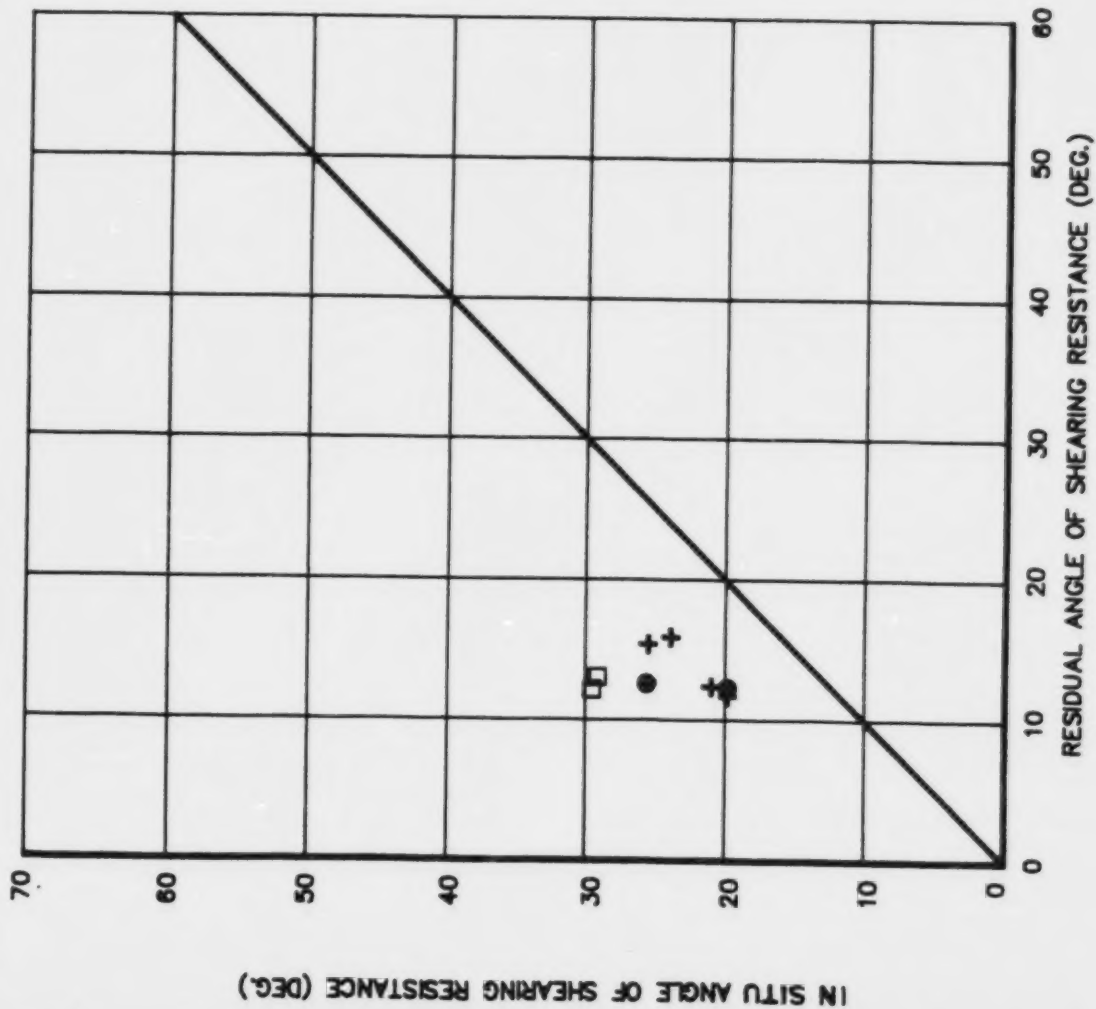
-  INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
-  SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
-  SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

Ariston

**SHEAR STRENGTH-IN SITU
SEAM R8**

PLATE B-161

SHEAR STRENGTH - IN SITU
SEAM NO. R8
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +

IN SITU ANGLE OF SHEARING RESISTANCE (DEG.)

RESIDUAL ANGLE OF SHEARING RESISTANCE (DEG.)

IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE

SEAM NO. R6

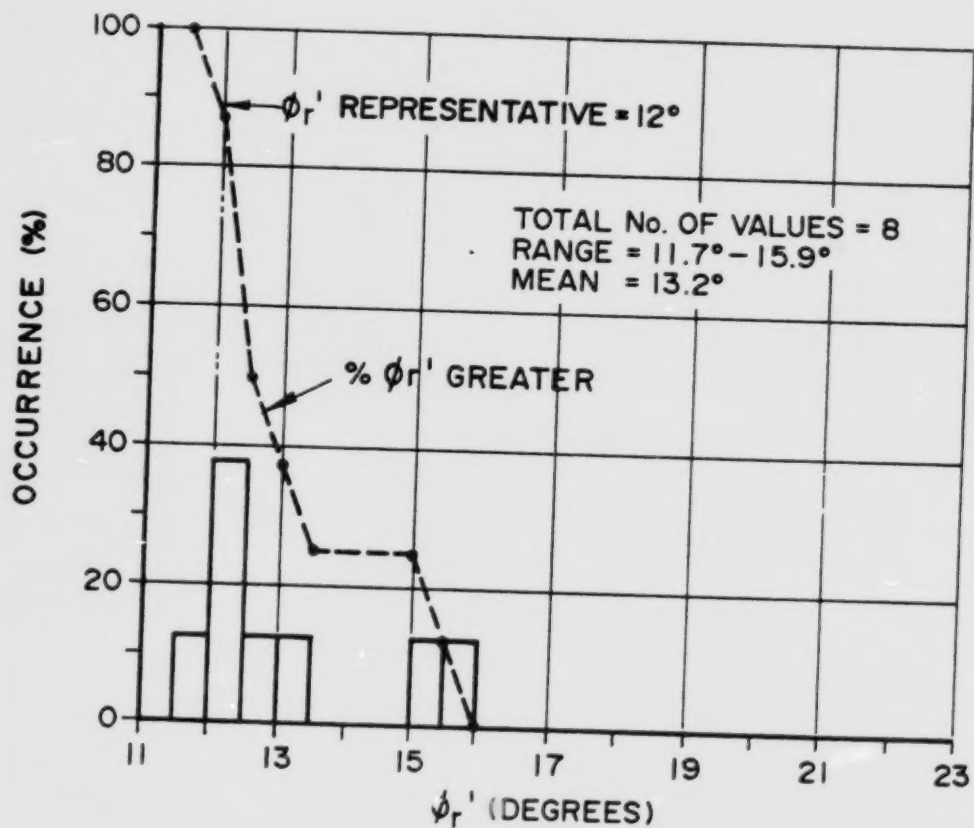
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



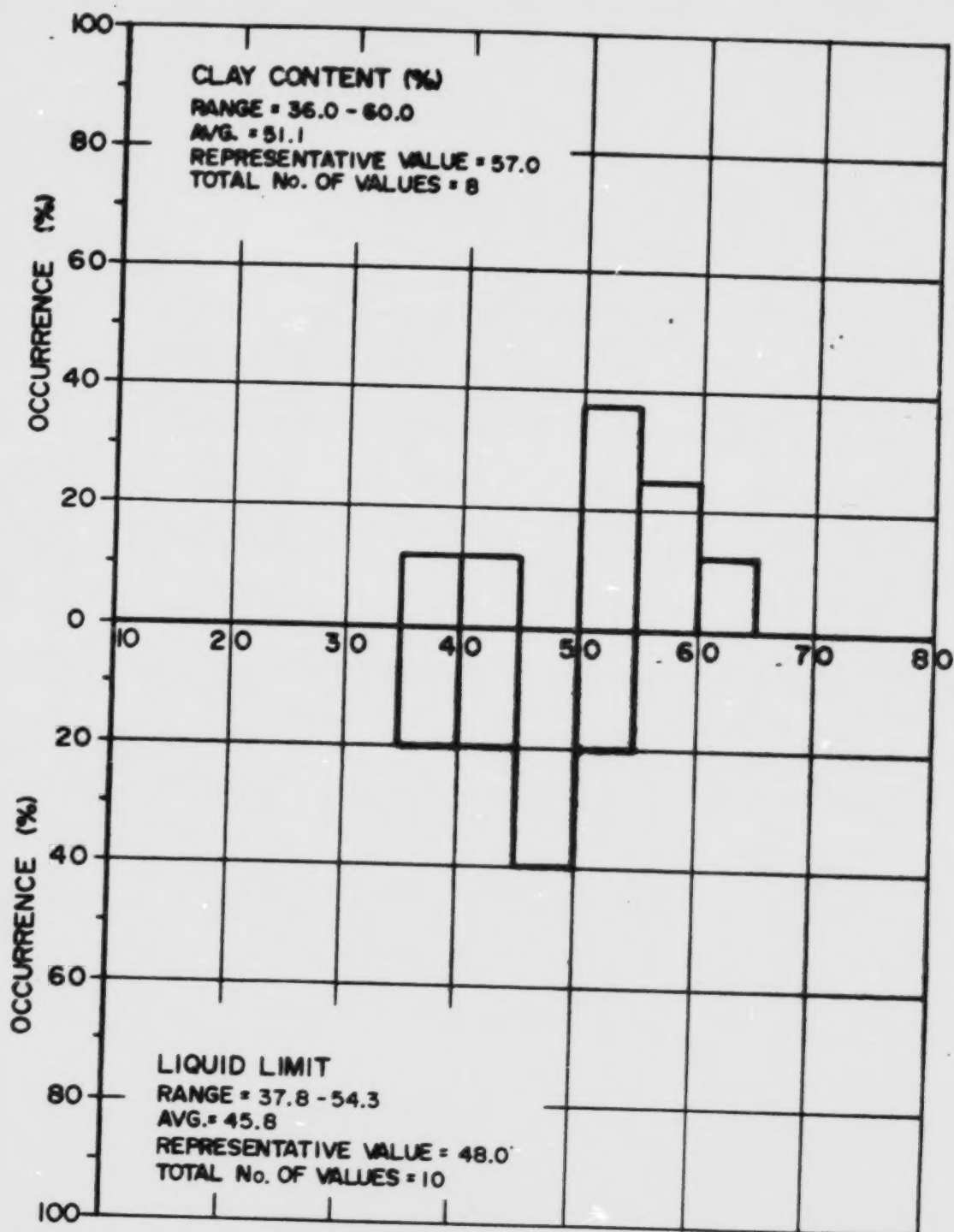
IN SITU VS ϕ'

SEAM R6

PLATE B-162



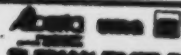
HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. R8
 REFERENCE ELEVATION AT SPILLWAY $\zeta = 1087.5\text{m}$

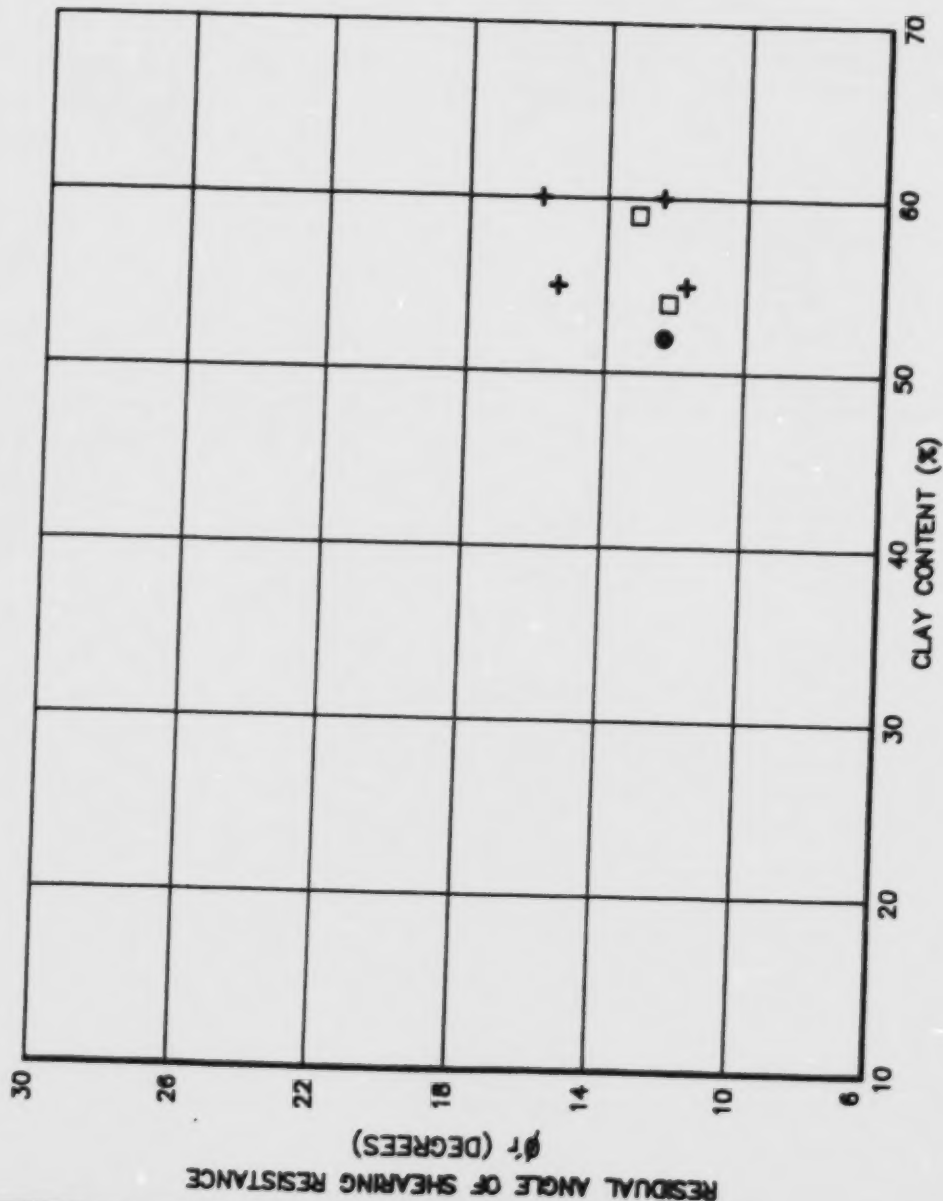


HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT

SEAM No. R8

REFERENCE ELEVATION AT SPILLWAY ζ = 1087.5m

GLS  
 GLS ENGINEERING & CONSTRUCTION
 HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM R8
PLATE B-164



LEGEND:

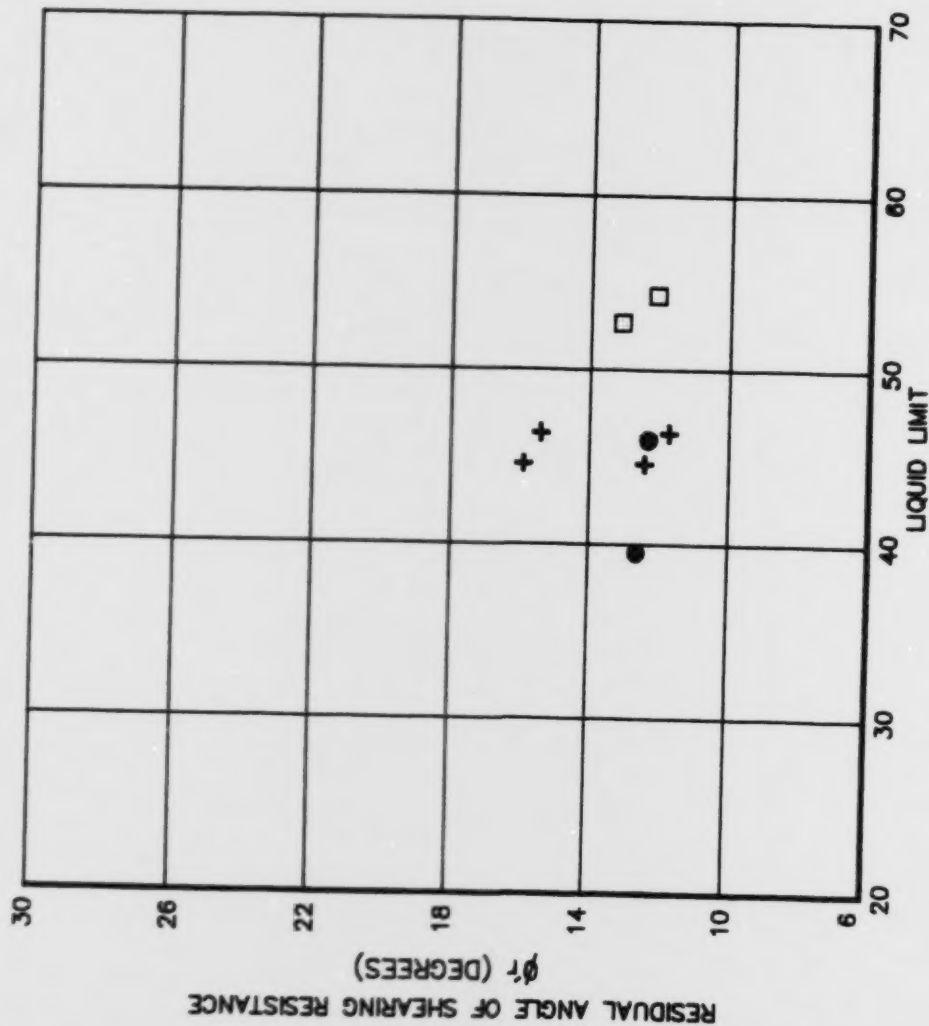
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +

SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r VS CLAY CONTENT
SEAM R8

RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM No. R8
REFERENCE ELEVATION AT SPILLWAY $\phi_c = 1087.5$ m



LEGEND:

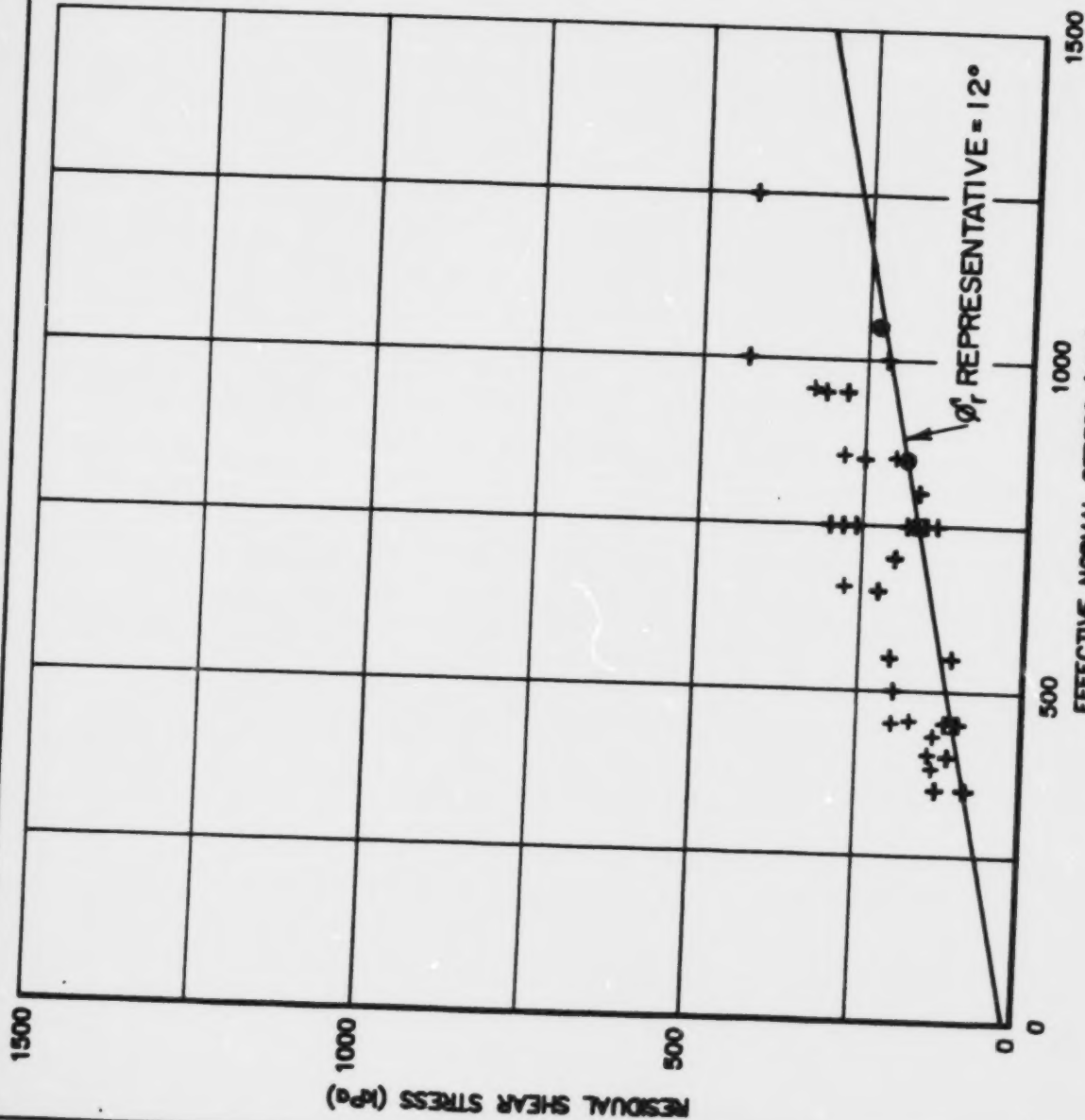
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
 - - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
 - +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs LIQUID LIMIT
SEAM R8

PLATE B-166

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM No R8
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING, 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST.
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 5 cm DIRECT SHEAR TEST.

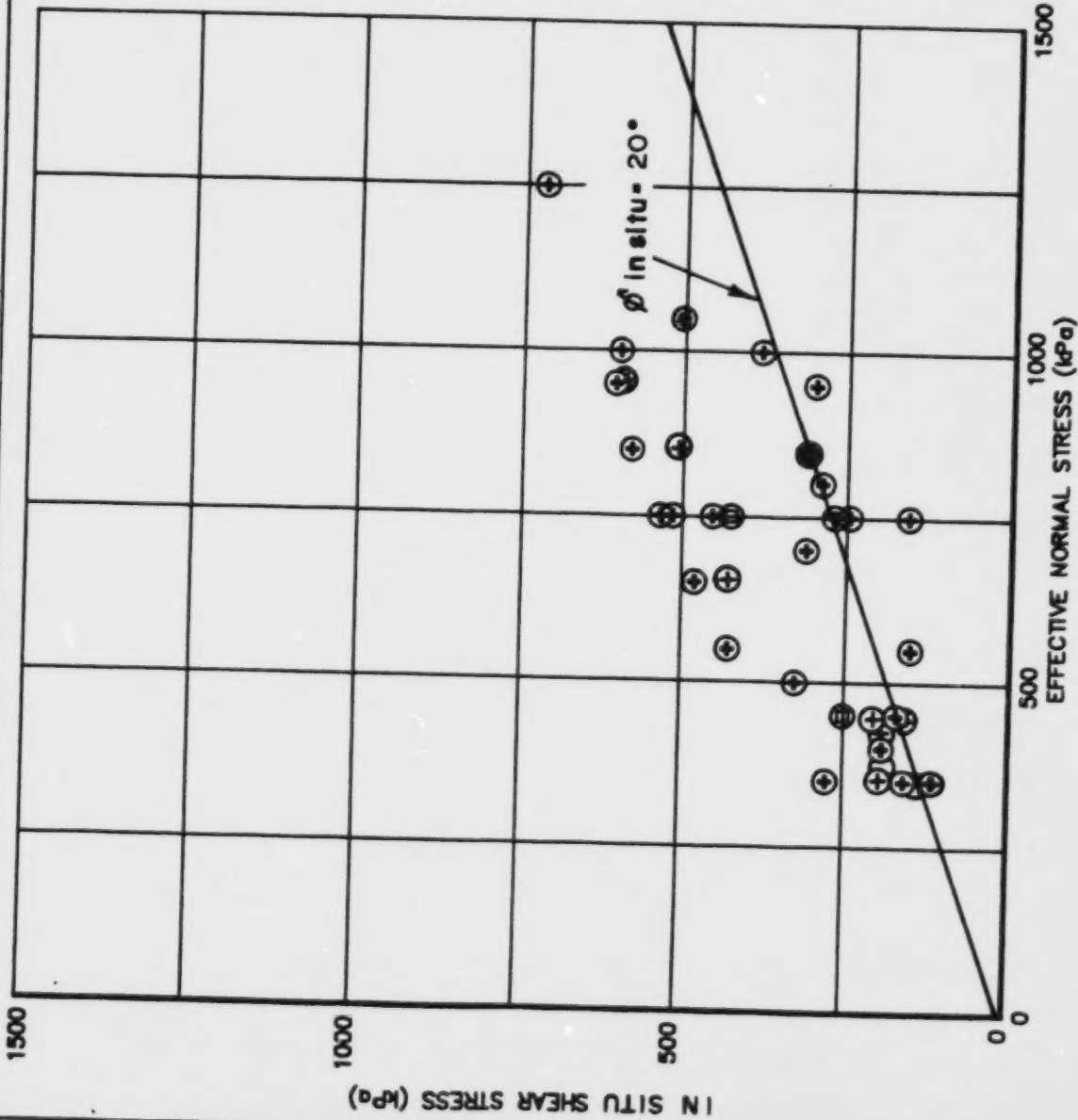
EFFECTIVE NORMAL STRESS (kPa)
SHEAR STRENGTH - RESIDUAL
SEAM No. R8

(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\bar{c}$ = 1087.5 m



SHEAR STRENGTH - RESIDUAL
SEAM No. R8

PLATE B-167



LEGEND:

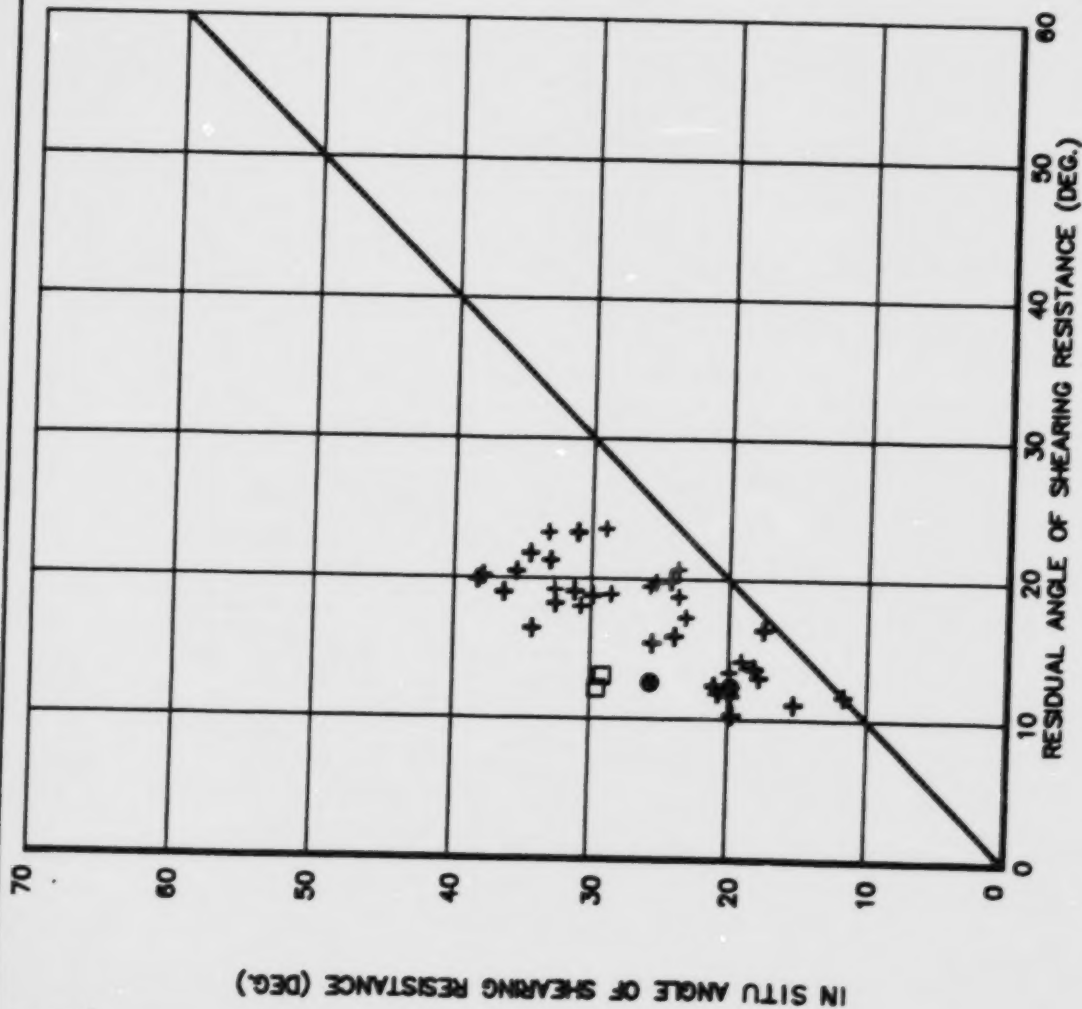
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



SHEAR STRENGTH - IN SITU
SEAM R8

PLATE B-168

SHEAR STRENGTH - IN SITU.
SEAM No R8
(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\ell = 1087.5$ m



LEGEND:

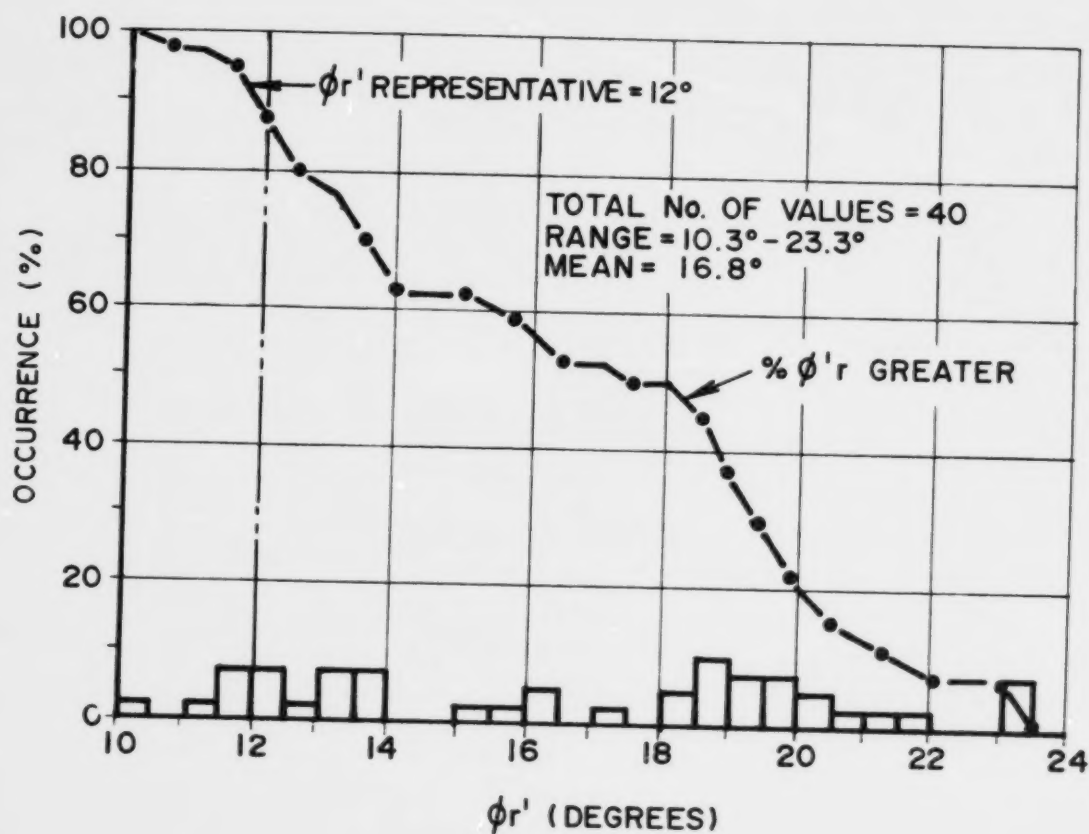
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +

SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

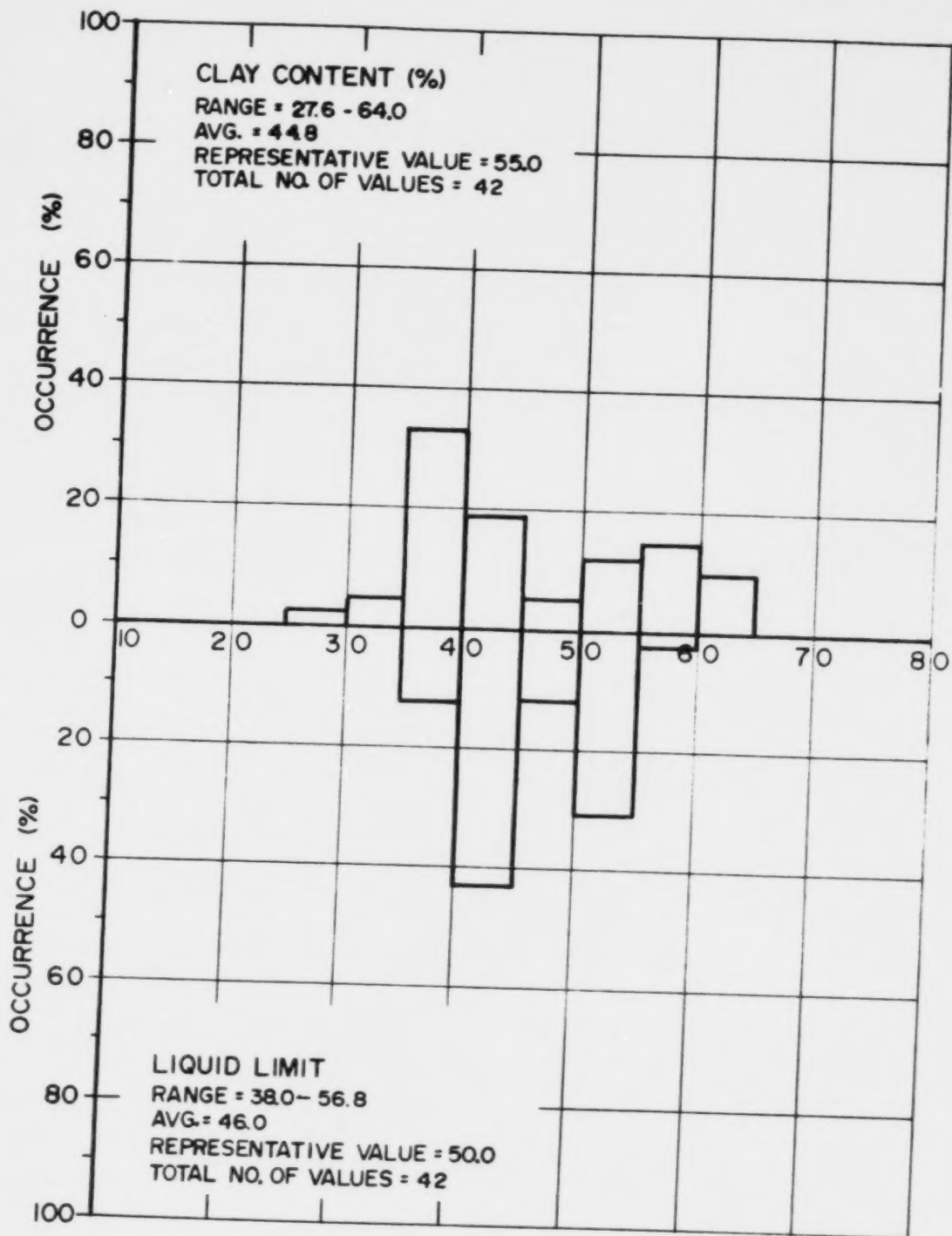


ϕ' IN SITU vs ϕ'
SEAM R8

IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO R8
(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. R8
 (INCLUDING RESULTS FROM UPSTREAM DIVERSION
 TUNNEL PORTAL)
 REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5\text{m}$

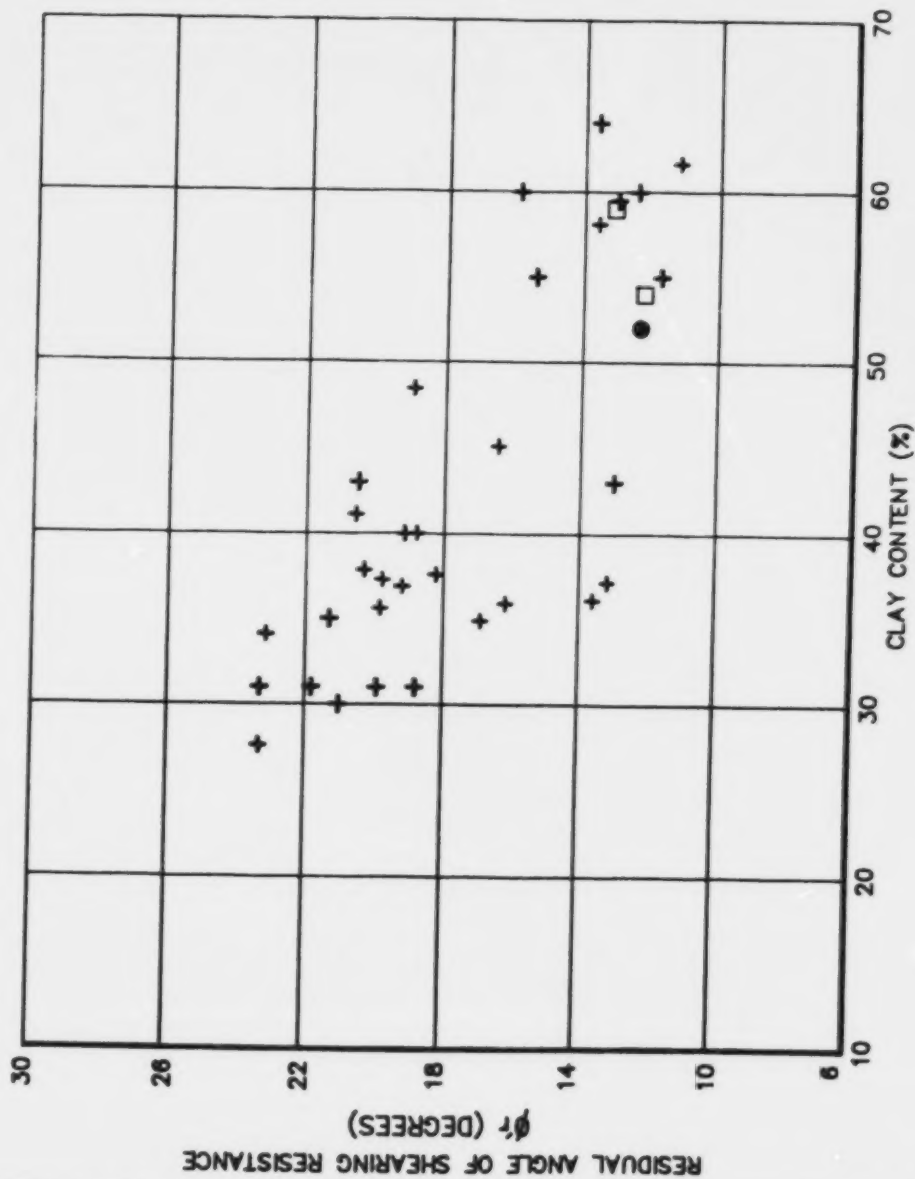


**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM NO. R8
 INCLUDING RESULTS FROM
 UPSTREAM DIVERSION TUNNEL PORTAL
 REFERENCE ELEVATION AT SPILLWAY ζ = 1087.5m**

Abeng  **uma**
 A DIVISION OF
OLDMAN RIVER DAM

**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM R8**

PLATE B-171

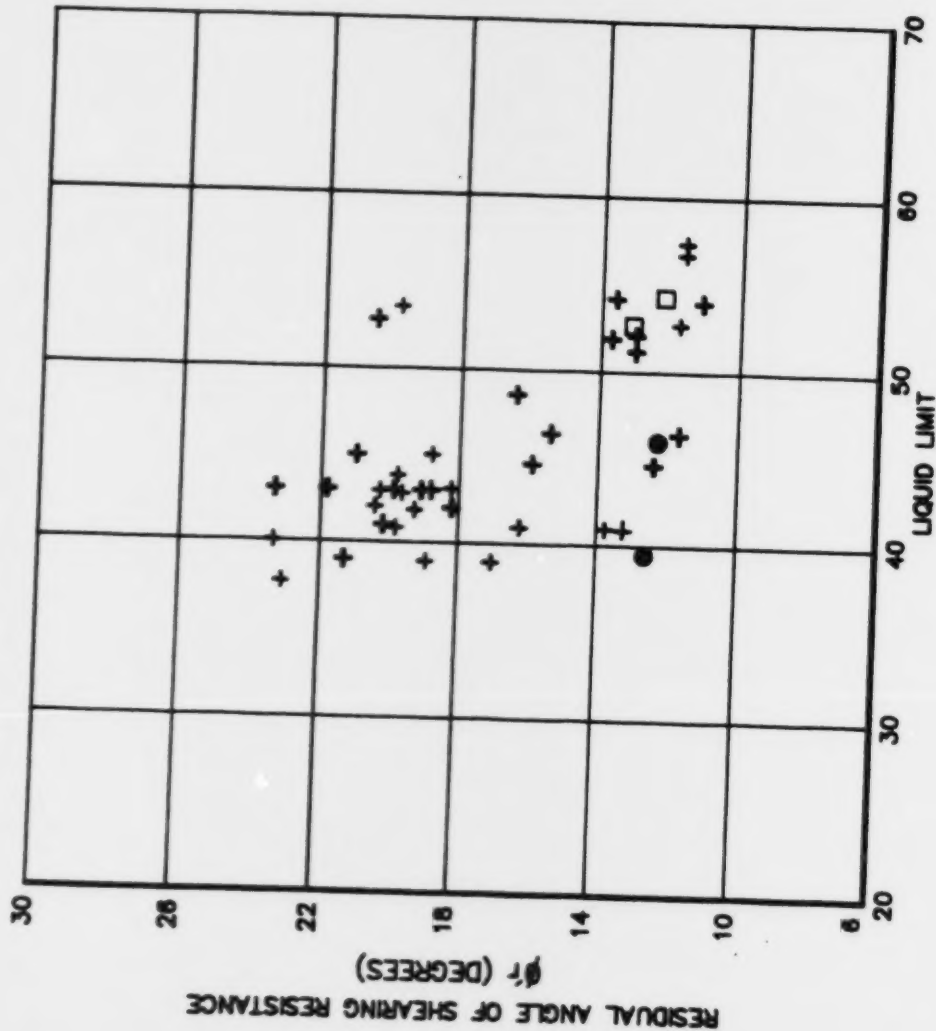


RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM NO. R8
(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\phi_c = 1087.5$ m



ϕ_r VS CLAY CONTENT
SEAM R8

PLATE B-172

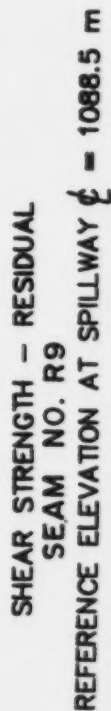


RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM NO. R8
(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



ϕ_r vs LIQUID LIMIT
SEAM R8

PLATE B-173

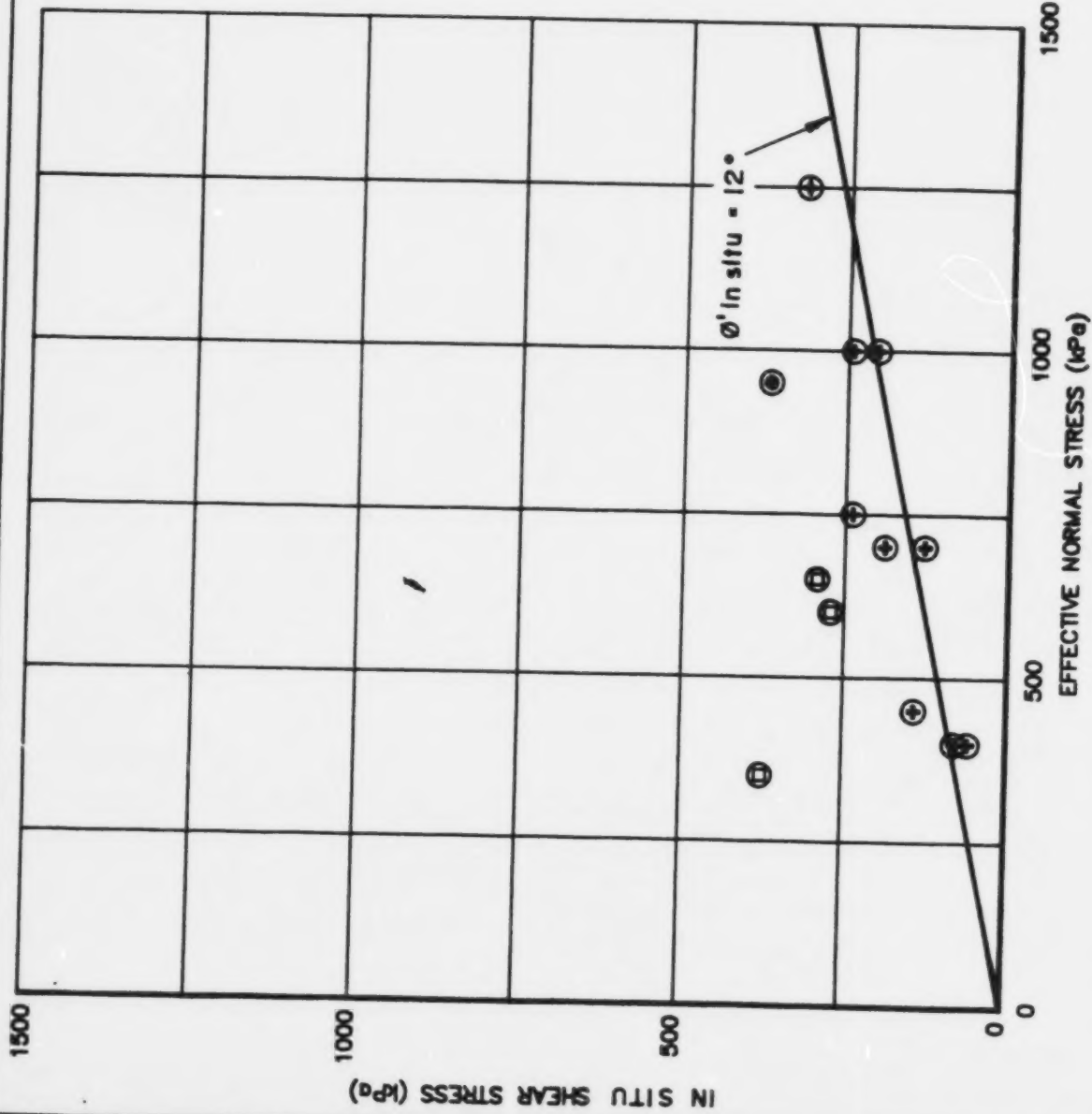


- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

[illegible]

SHEAR STRENGTH - RESIDUAL
SEAM R9

PLATE B-174



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- ⊕ - 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



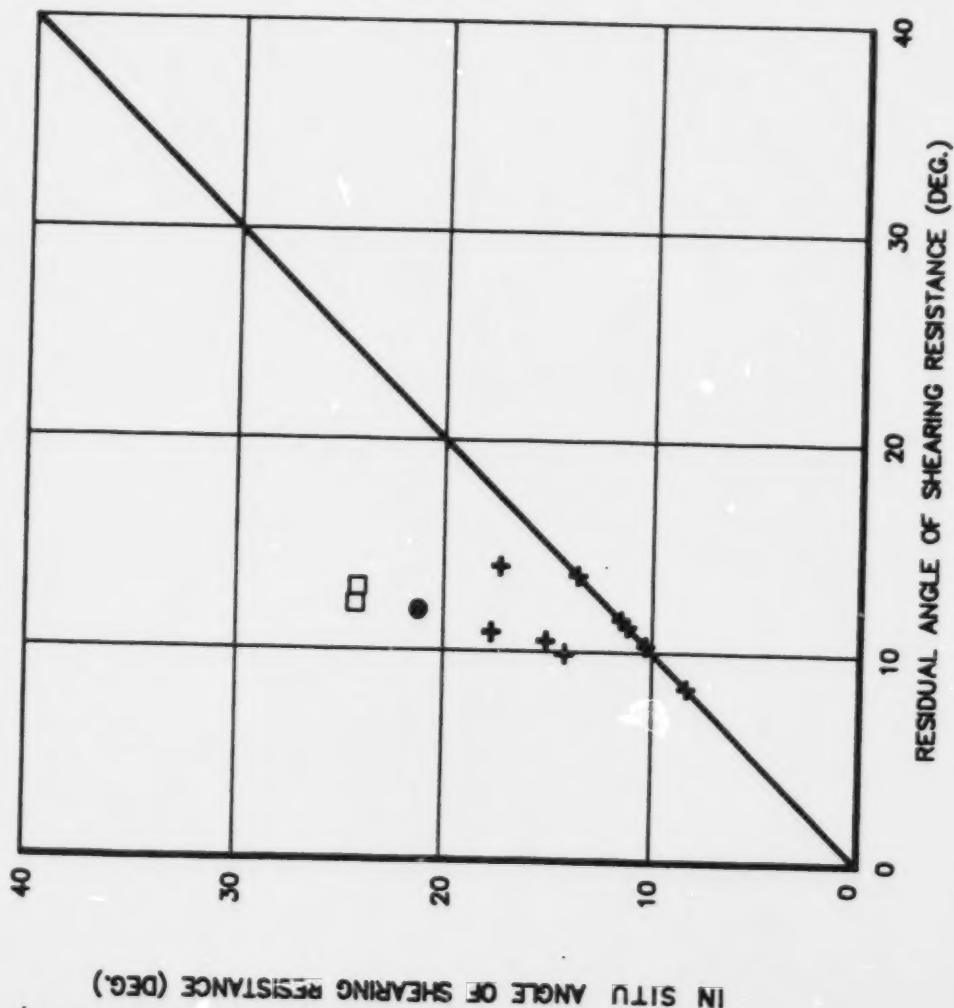
SHEAR STRENGTH - IN SITU
SEAM R9

PLATE B-175

SHEAR STRENGTH - IN SITU
SEAM NO. R9

REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m

- LEGEND:
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
 - - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
 - +
 - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

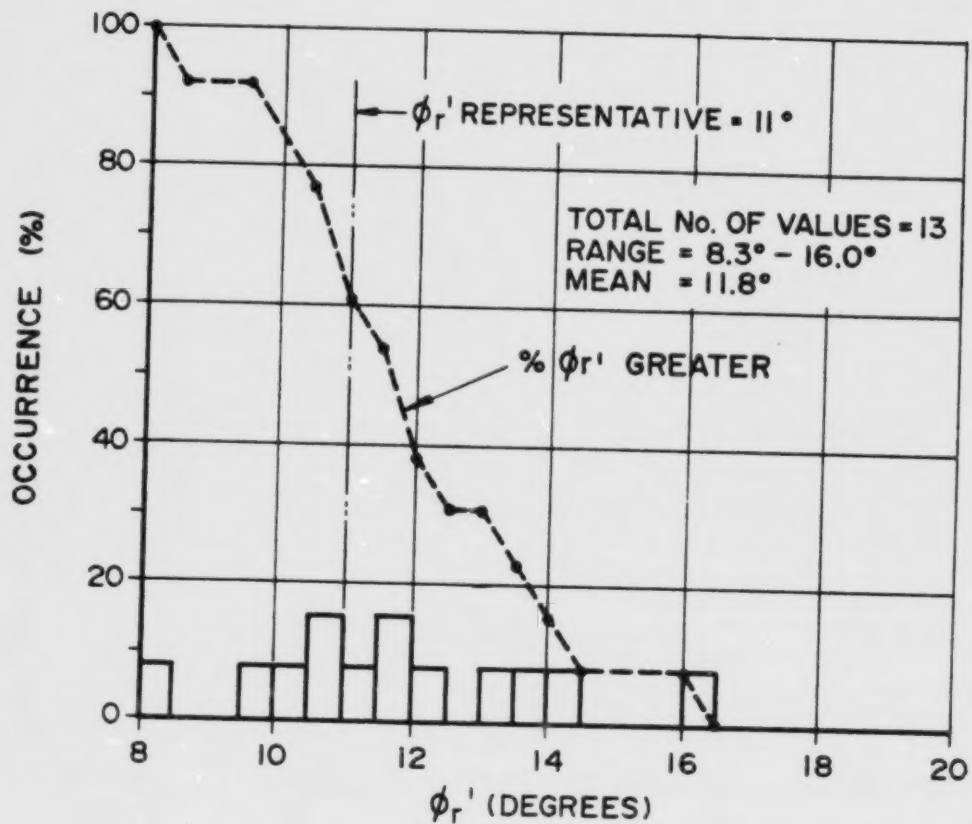


IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO. R9
REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m

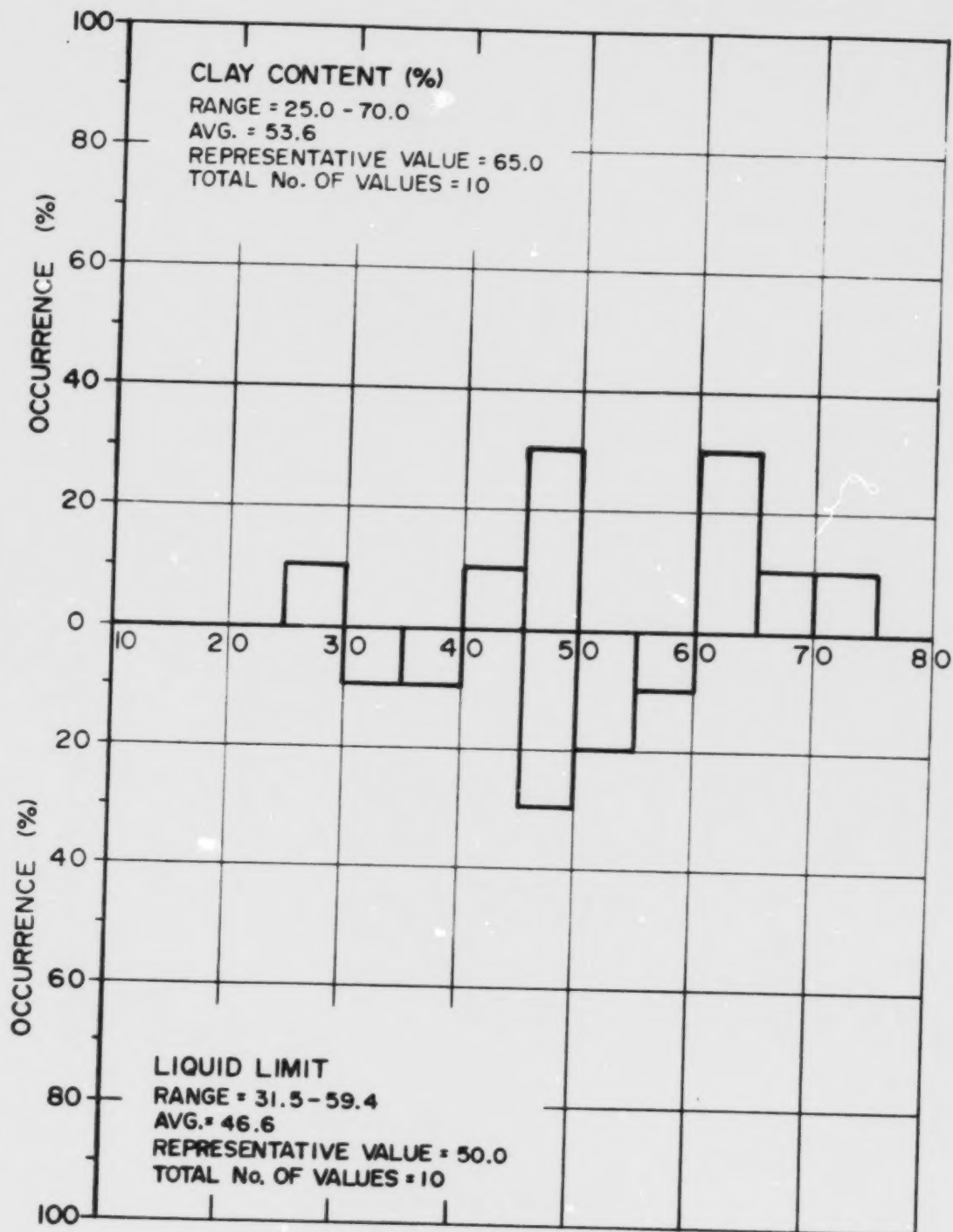


ϕ' in situ vs ϕ'
SEAM R9

PLATE B-176



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM NO. R9
 REFERENCE ELEVATION AT SPILLWAY $\mathcal{L}$ = 1088.5m



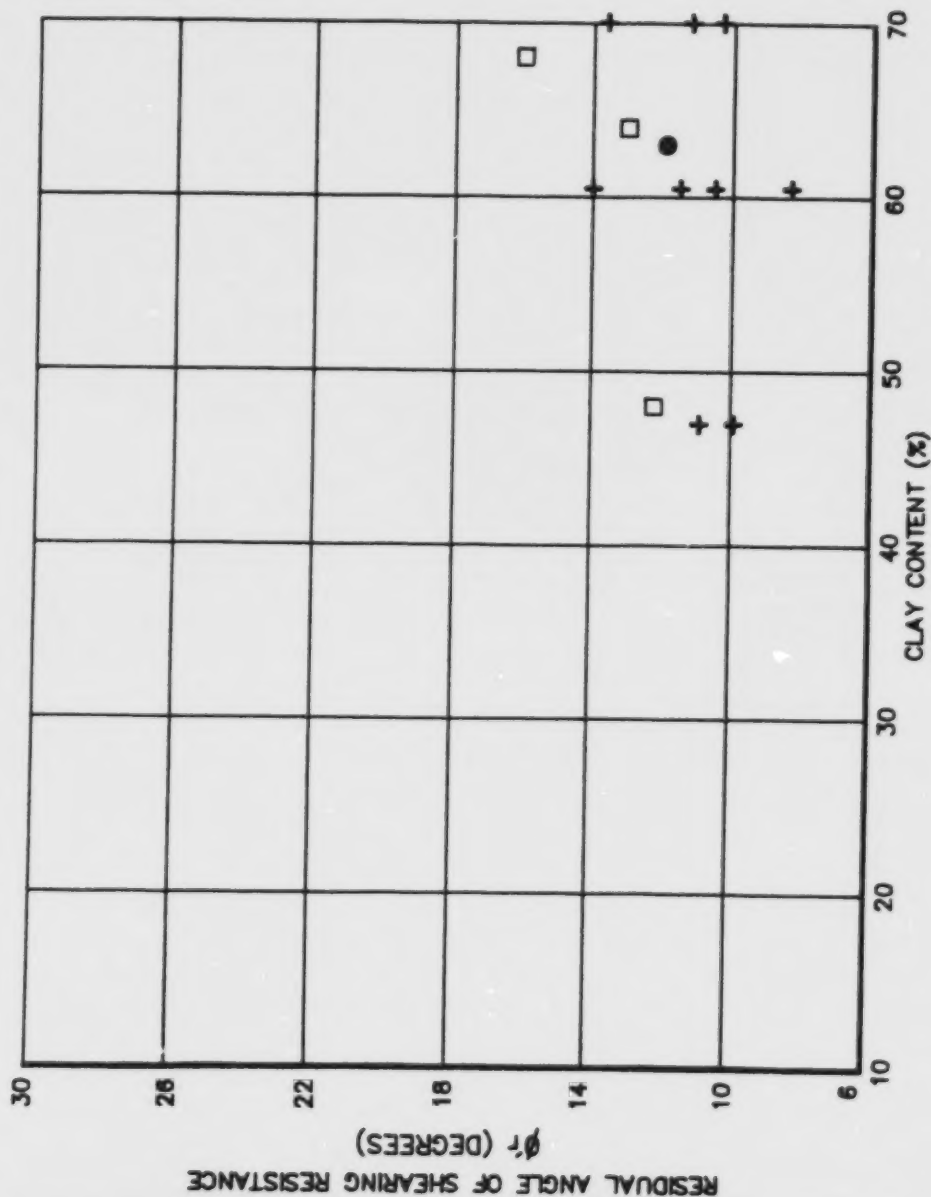
**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM NO. R9**

REFERENCE ELEVATION AT SPILLWAY ζ = 1088.5m

ASPECT **ENGINEERING INC.**
CLERMONT RIVER DAM

**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM R9**

PLATE B-178



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

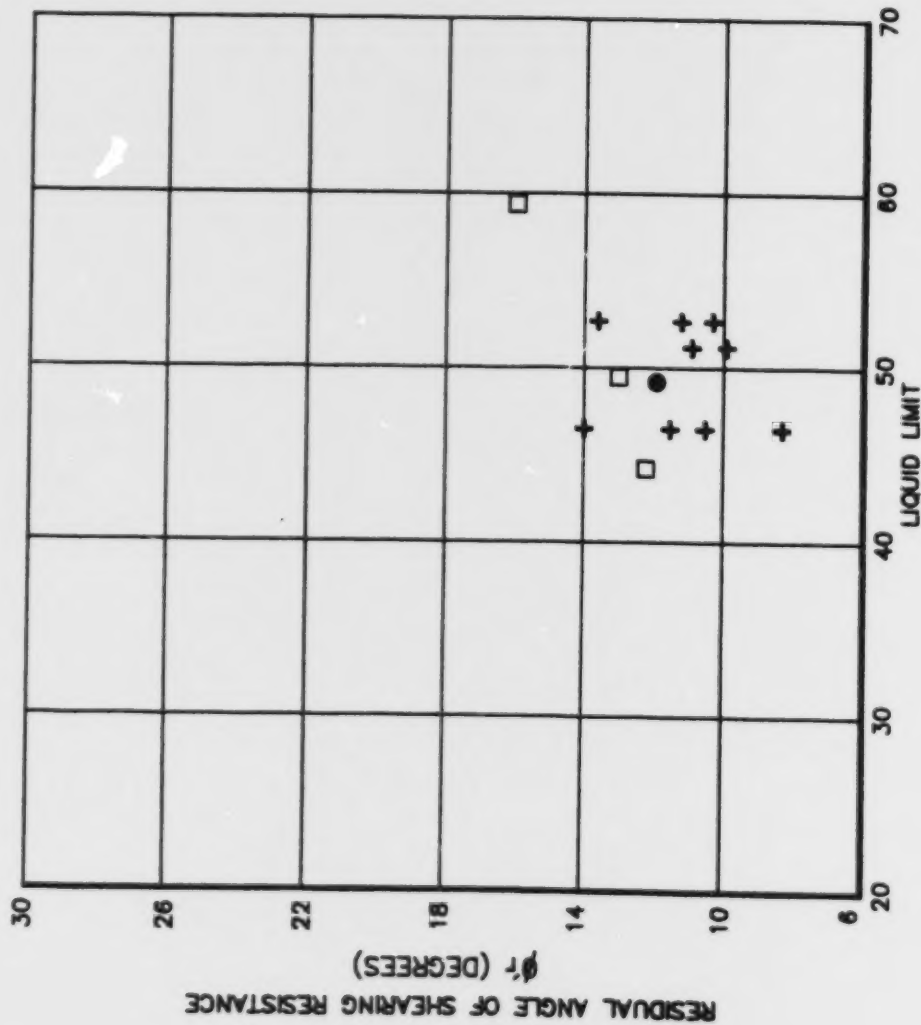


RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM NO. R9

REFERENCE ELEVATION AT SPILLWAY $\phi_c = 1088.5$ m

ϕ_r VS CLAY CONTENT
SEAM R9

PLATE B-179



LEGEND:

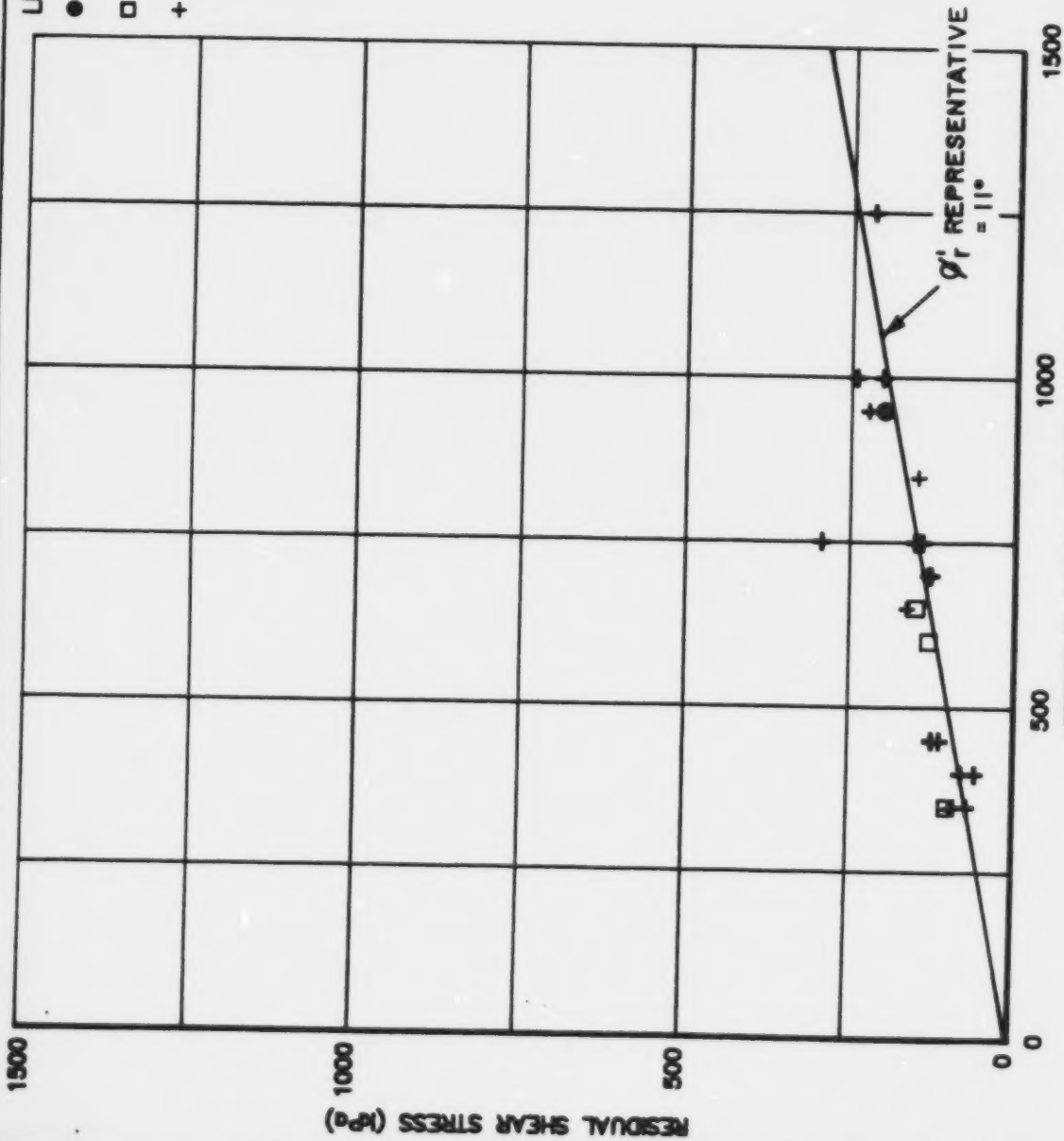
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +
- +
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs LIQUID LIMIT
SEAM R9

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM NO. R9
REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m

PLATE B-180



LEGEND:

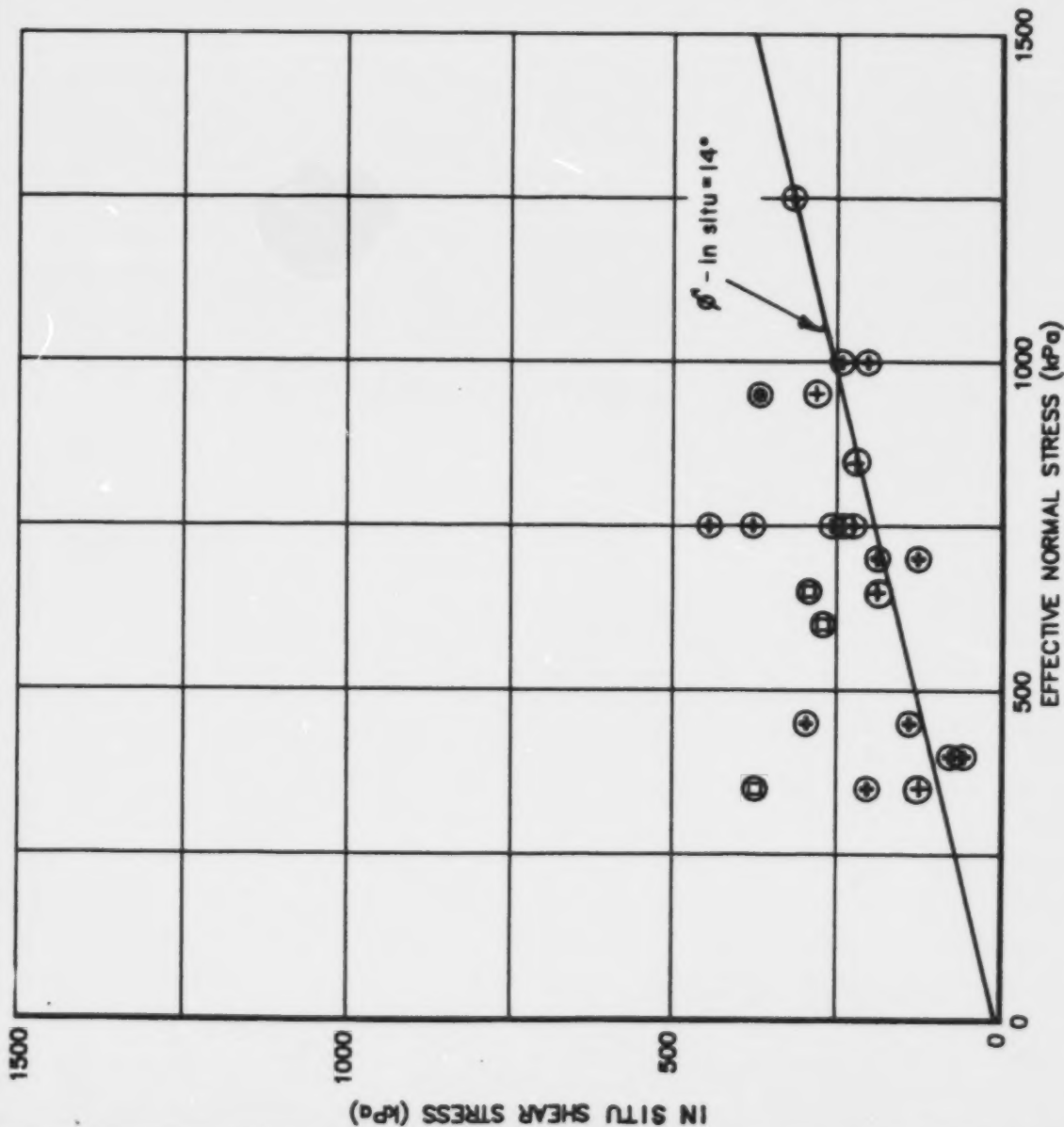
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING, 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST.
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 5 cm DIRECT SHEAR TEST.

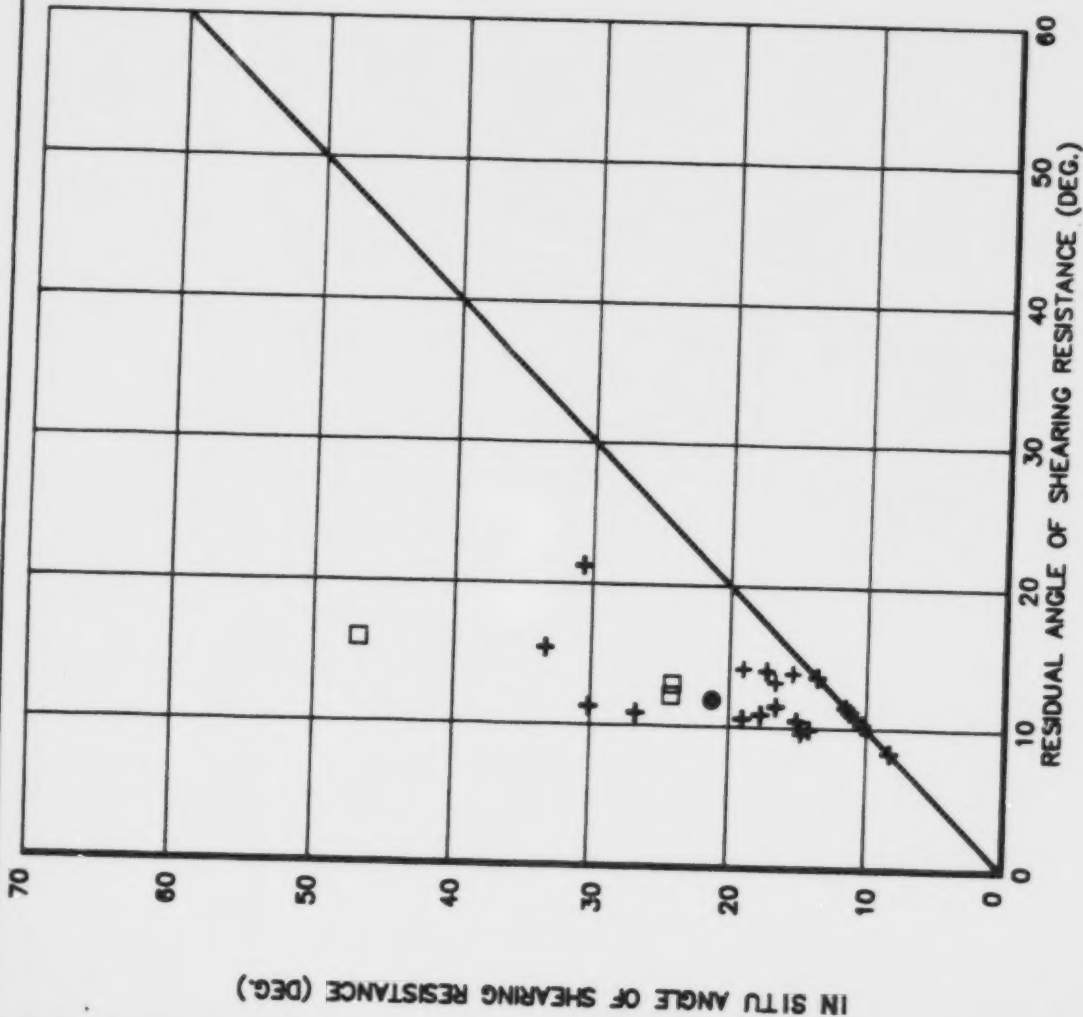


SHEAR STRENGTH - RESIDUAL
SEAM R9

PLATE B-181

(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\bar{c}$ = 1088.5 m





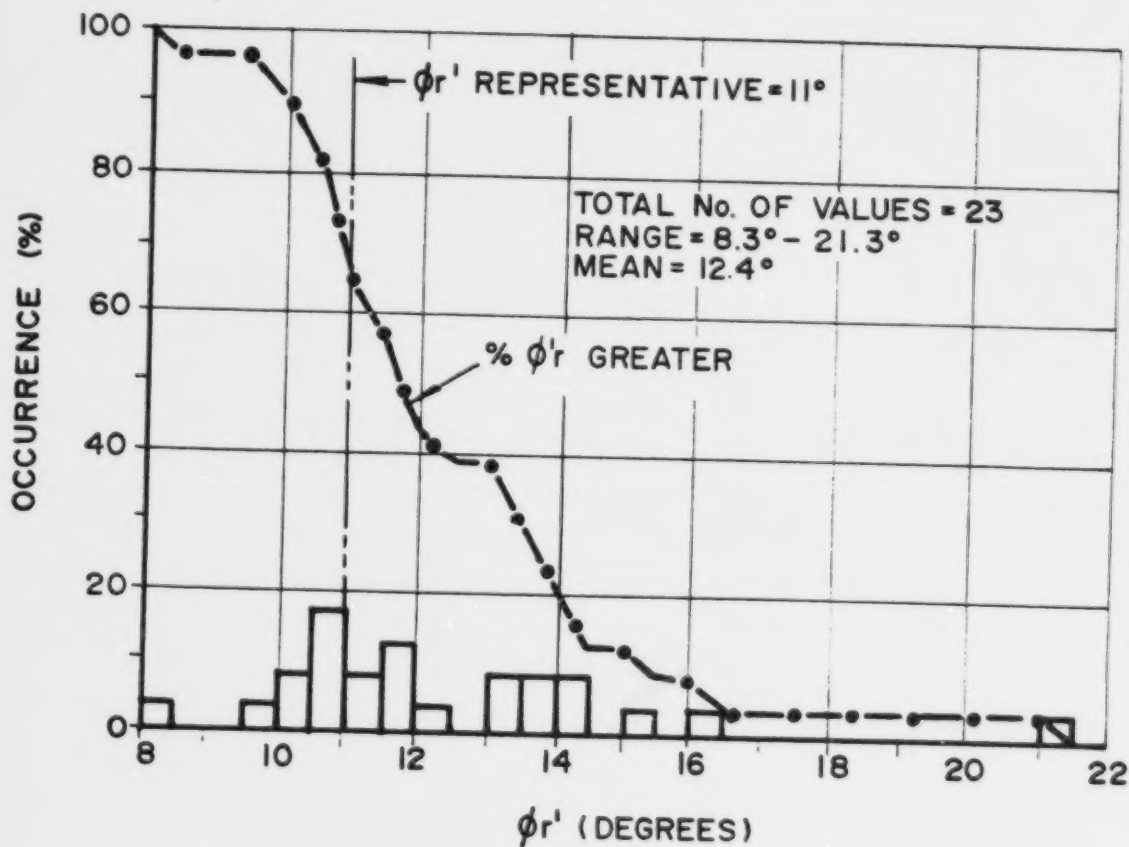
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

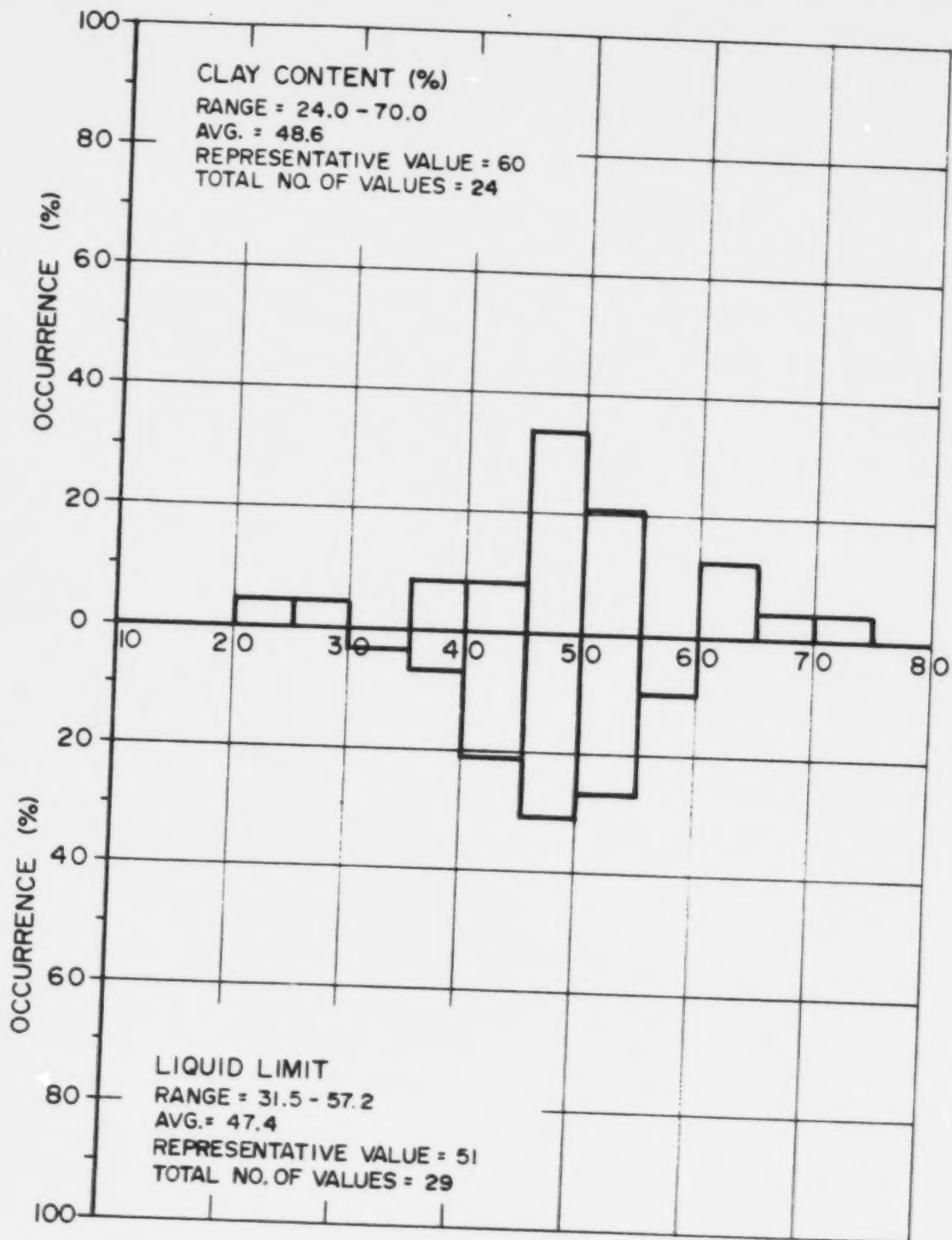


ϕ' - In situ vs ϕ_r
SEAM R9

IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM No. R9
(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. R9
 (INCLUDING RESULTS FROM UPSTREAM DIVERSION
 TUNNEL PORTAL)
 REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5\text{m}$

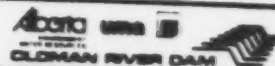


HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT

SEAM No. R9

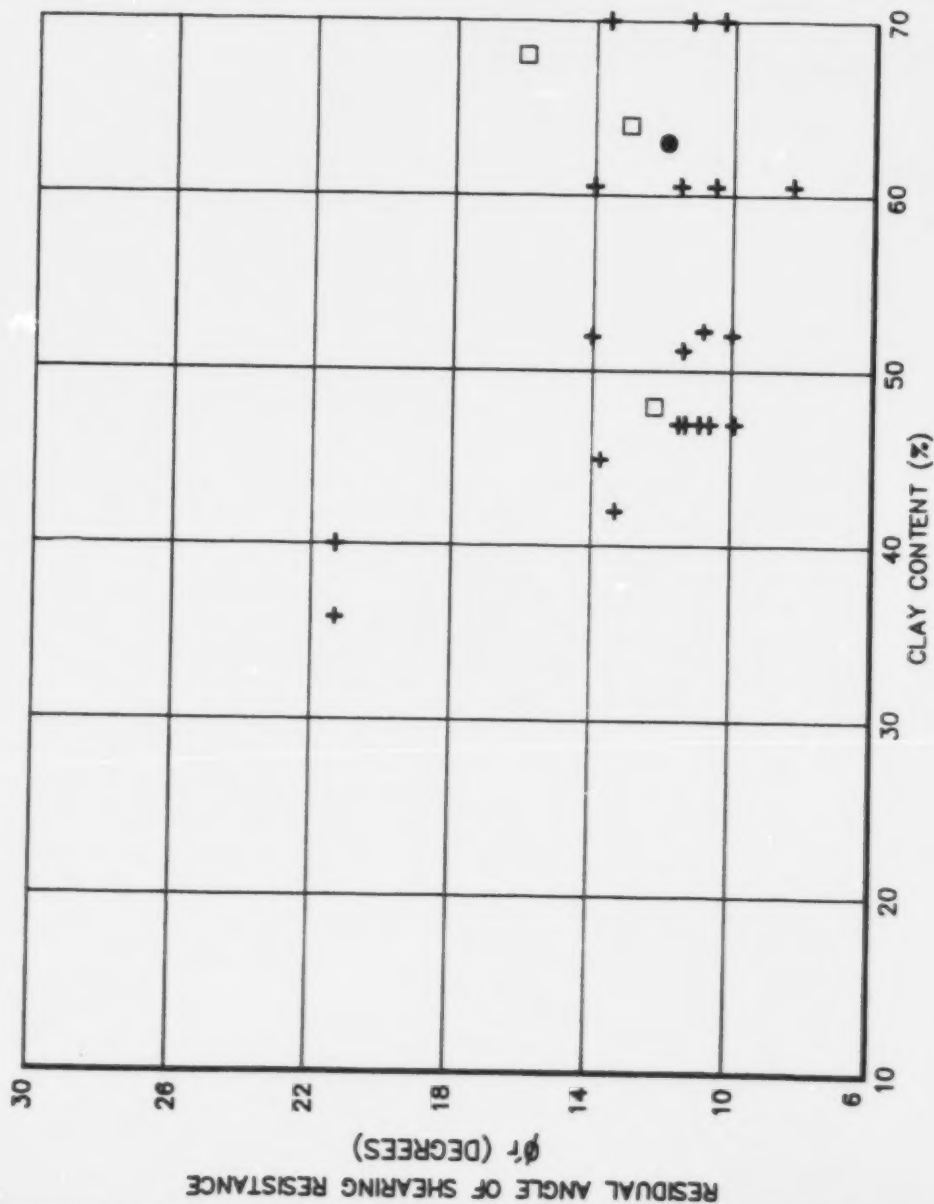
INCLUDING RESULTS FROM UPSTREAM
 DIVERSION TUNNEL PORTAL

REFERENCE ELEVATION AT SPILLWAY $Q_L = 1088.5m$



HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM R9

PLATE B-185



LEGEND:

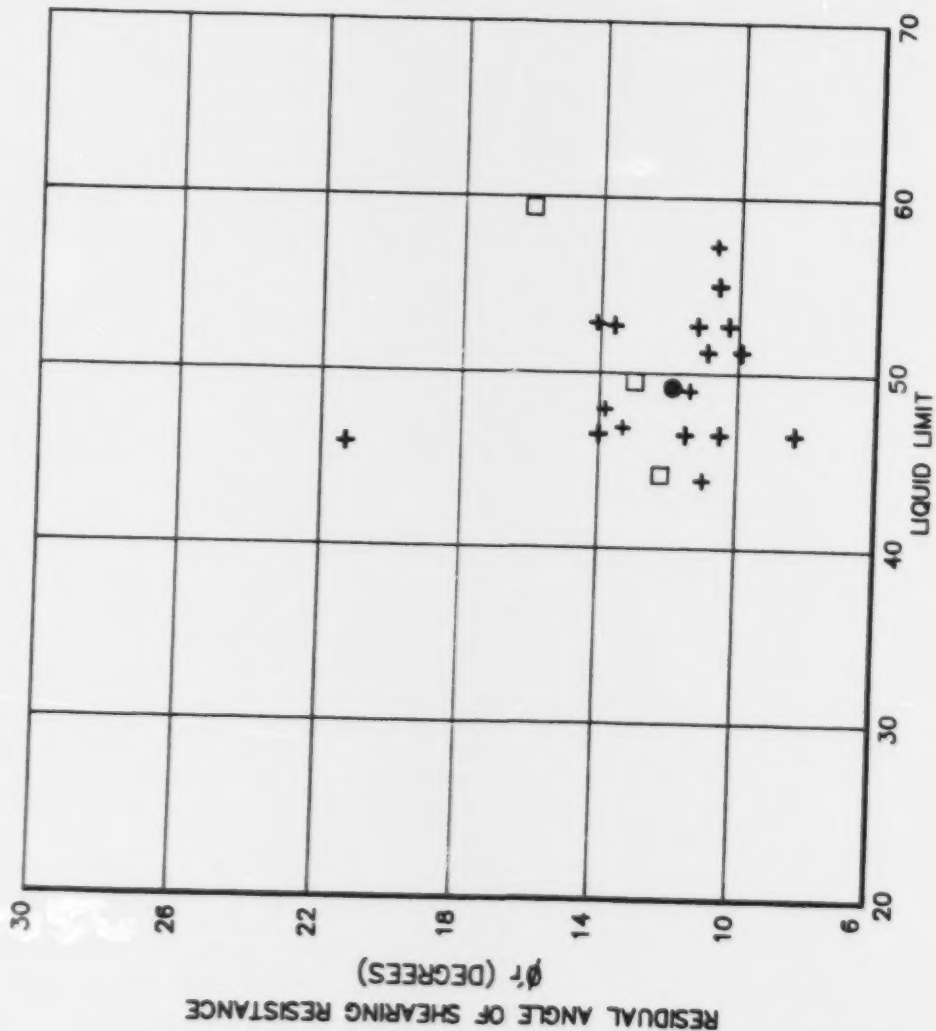
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
 - - 5 cm x 5 cm DIRECT SHEAR TEST
 - +
- SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



VS CLAY CONTENT
SEAM R9

PLATE B-186

RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM No. R9
(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\phi_c = 1088.5$ m

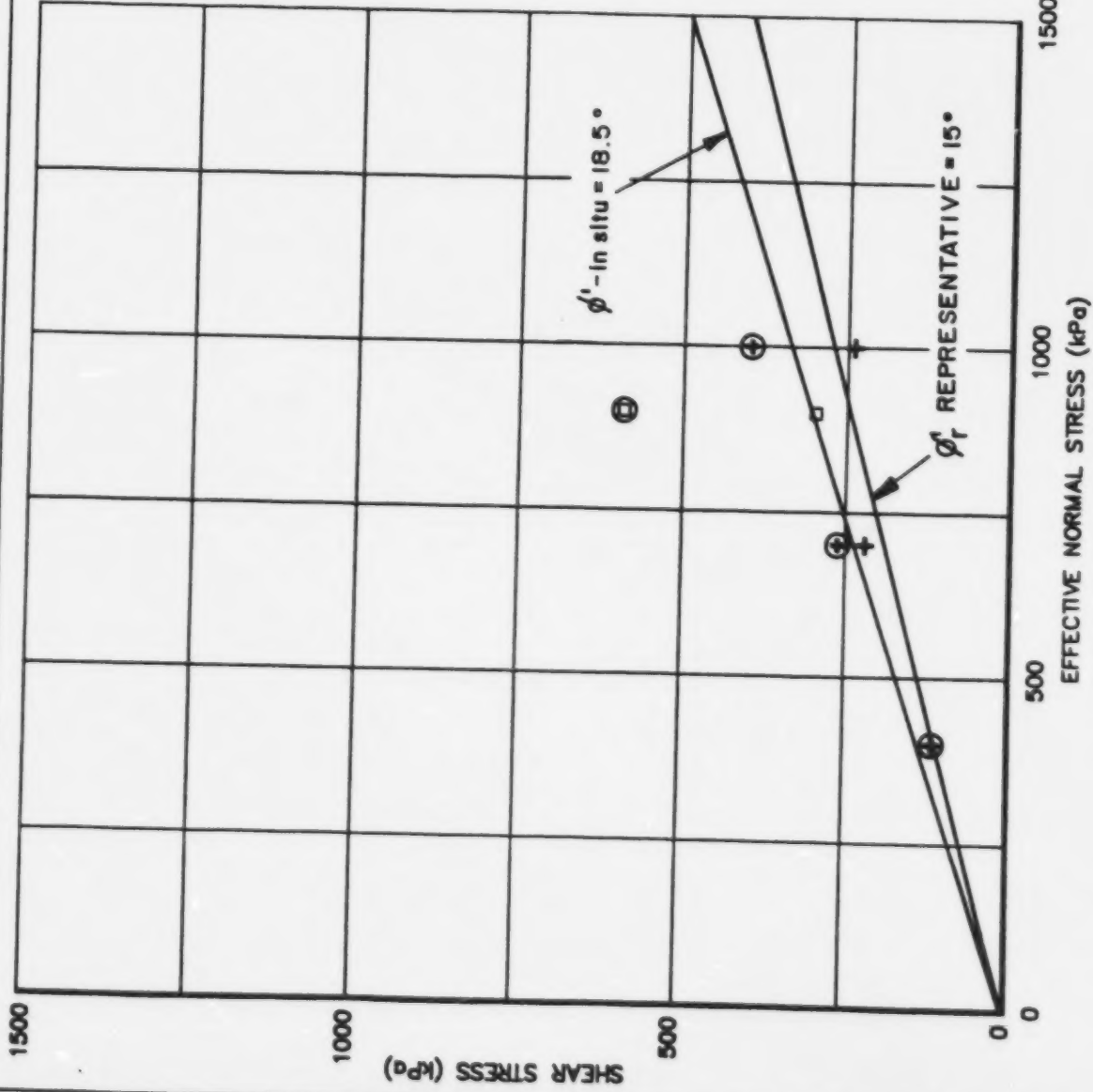


RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM No. R9
(INCLUDING RESULTS FROM UPSTREAM DIVERSION TUNNEL PORTAL)
REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m



ϕ_r vs LIQUID LIMIT
SEAM R9

PLATE B-187



LEGEND:

RESIDUAL

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

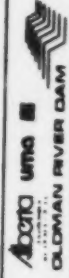
PEAK

- ⊙ - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

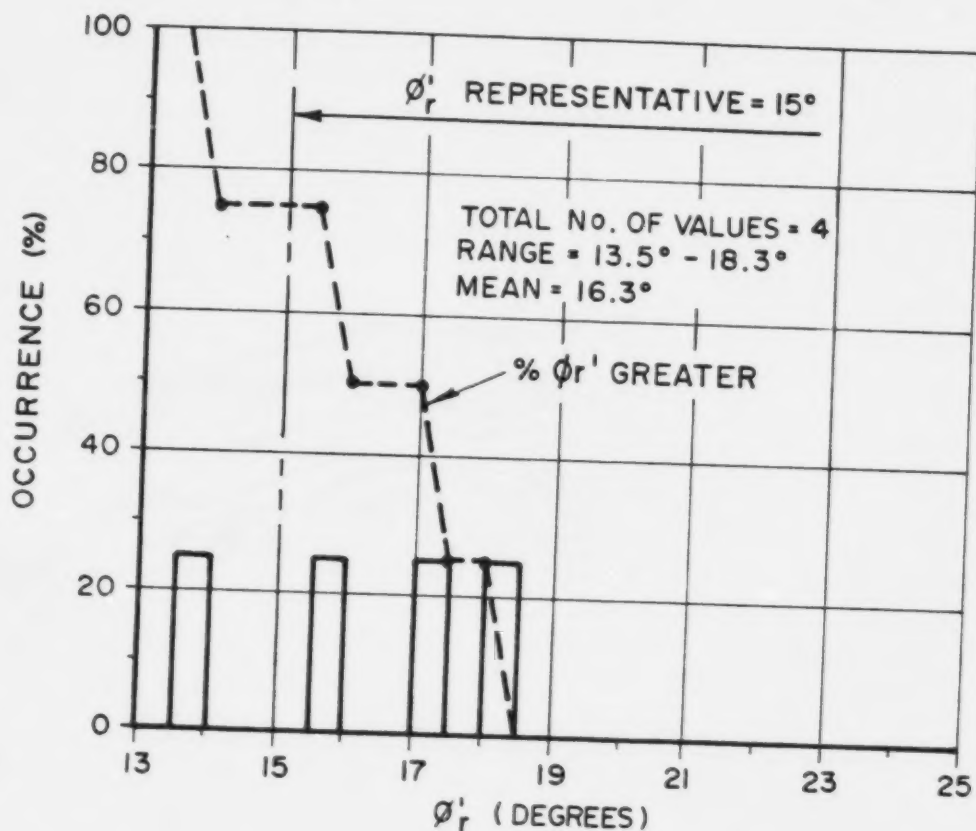
LL	C%
40.6	49.0
48.0	50.0
REPRESENTATIVE VALUES	
44.0	50.0

500 1000 1500
EFFECTIVE NORMAL STRESS (kPa)

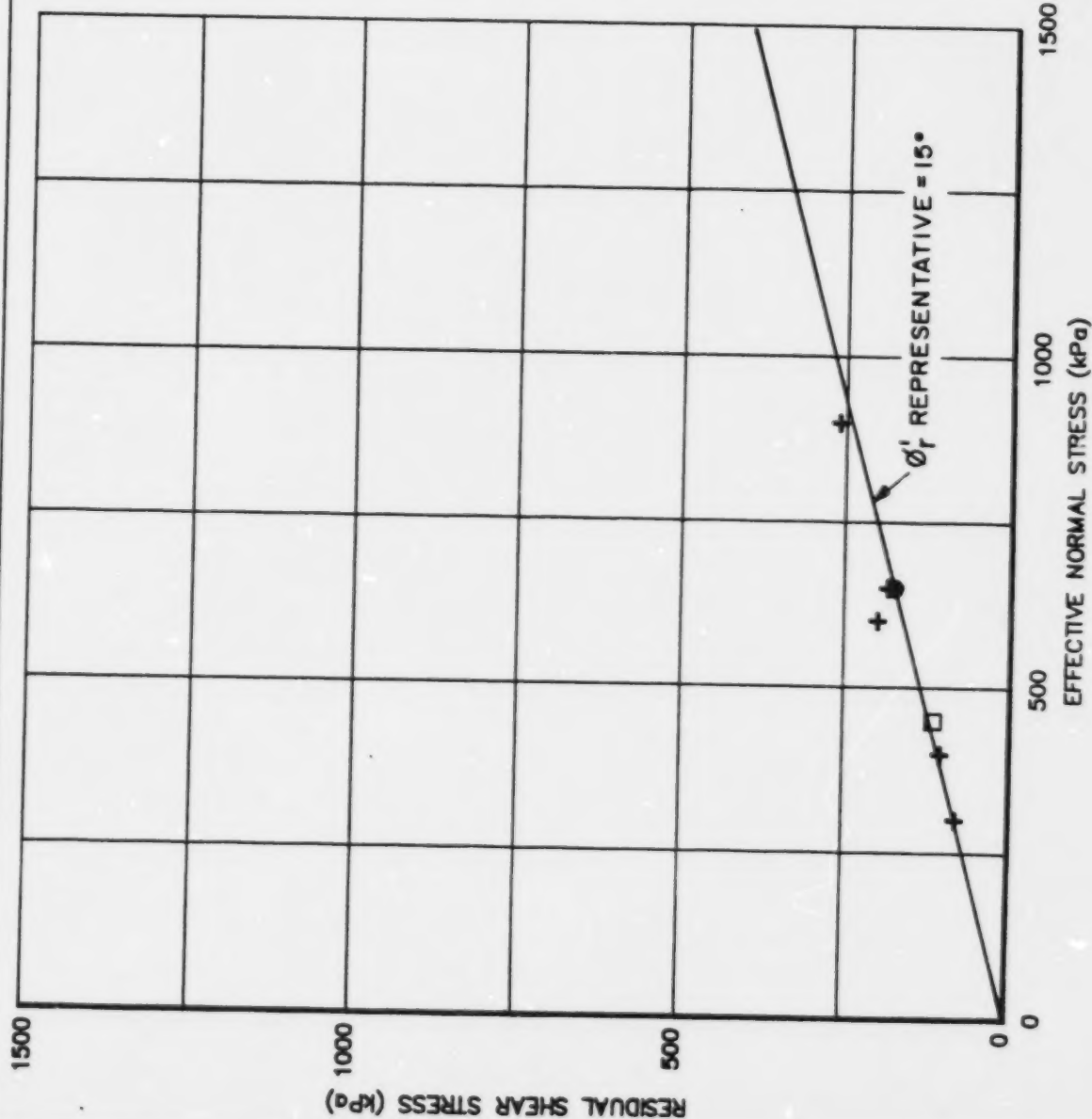
SHEAR STRENGTH - IN SITU AND RESIDUAL
SEAM No. R13
REFERENCE ELEVATION AT SPILLWAY $\phi = 1096.5\text{m}$



SHEAR STRENGTH - IN SITU
SEAM R13



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. R13
 REFERENCE ELEVATION AT SPILLWAY $\zeta = 1096.5\text{m}$



- LEGEND:**

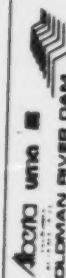
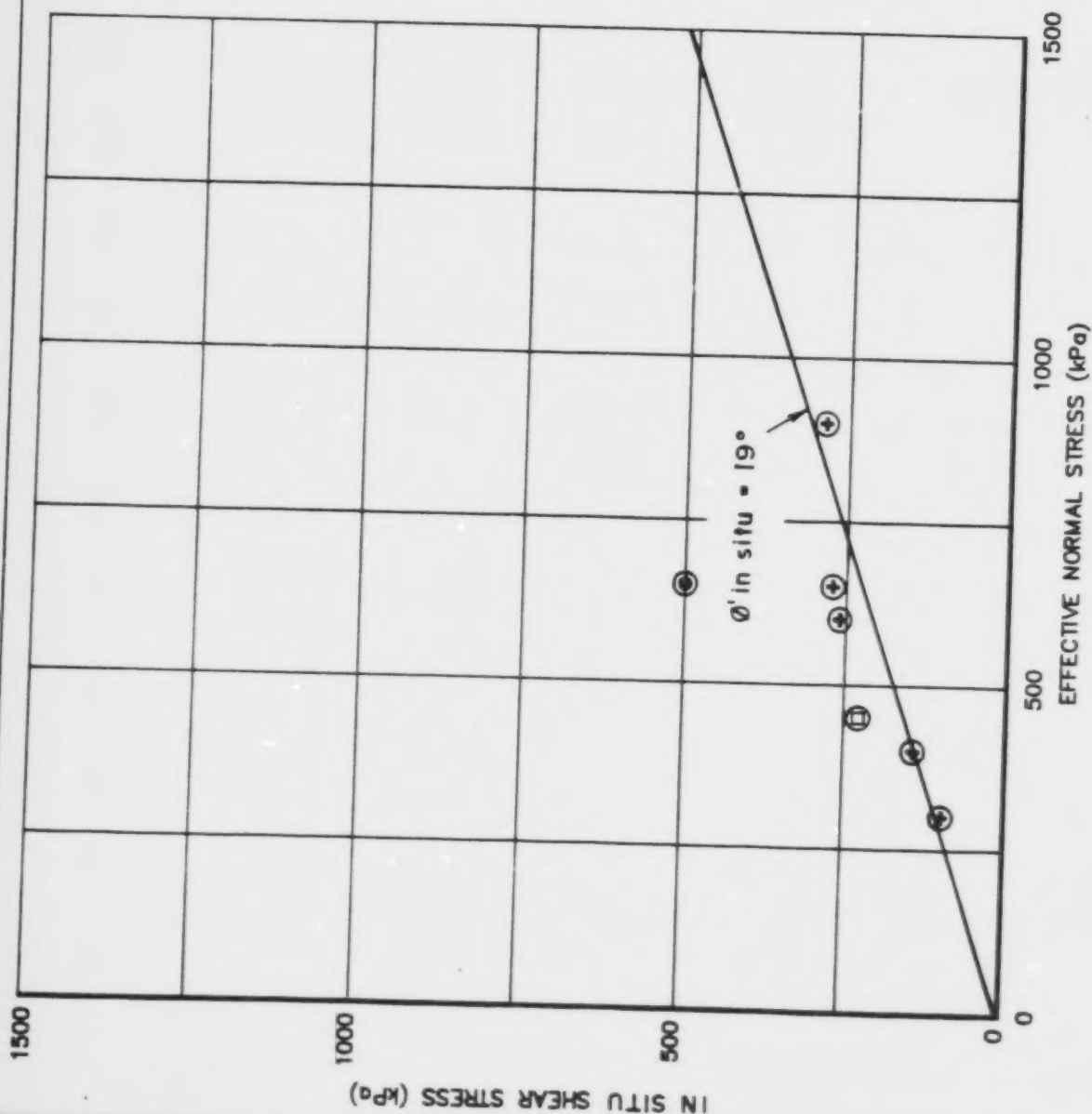
- | | | |
|---|---|---|
| ● | - | INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST |
| □ | - | SEAM SAMPLE OBTAINED FROM
DRILLHOLE, 5 cm x 5 cm DIRECT
SHEAR TEST |
| + | - | SEAM SAMPLE OBTAINED FROM
SHAFT OR TRENCH, 10 cm x 10 cm
DIRECT SHEAR TEST. |

[illegible]

SHEAR STRENGTH - RESIDUAL
SEAM R14

REFERENCE ELEVATION AT SPILLWAY $\phi = 1099.8 \text{ m}$

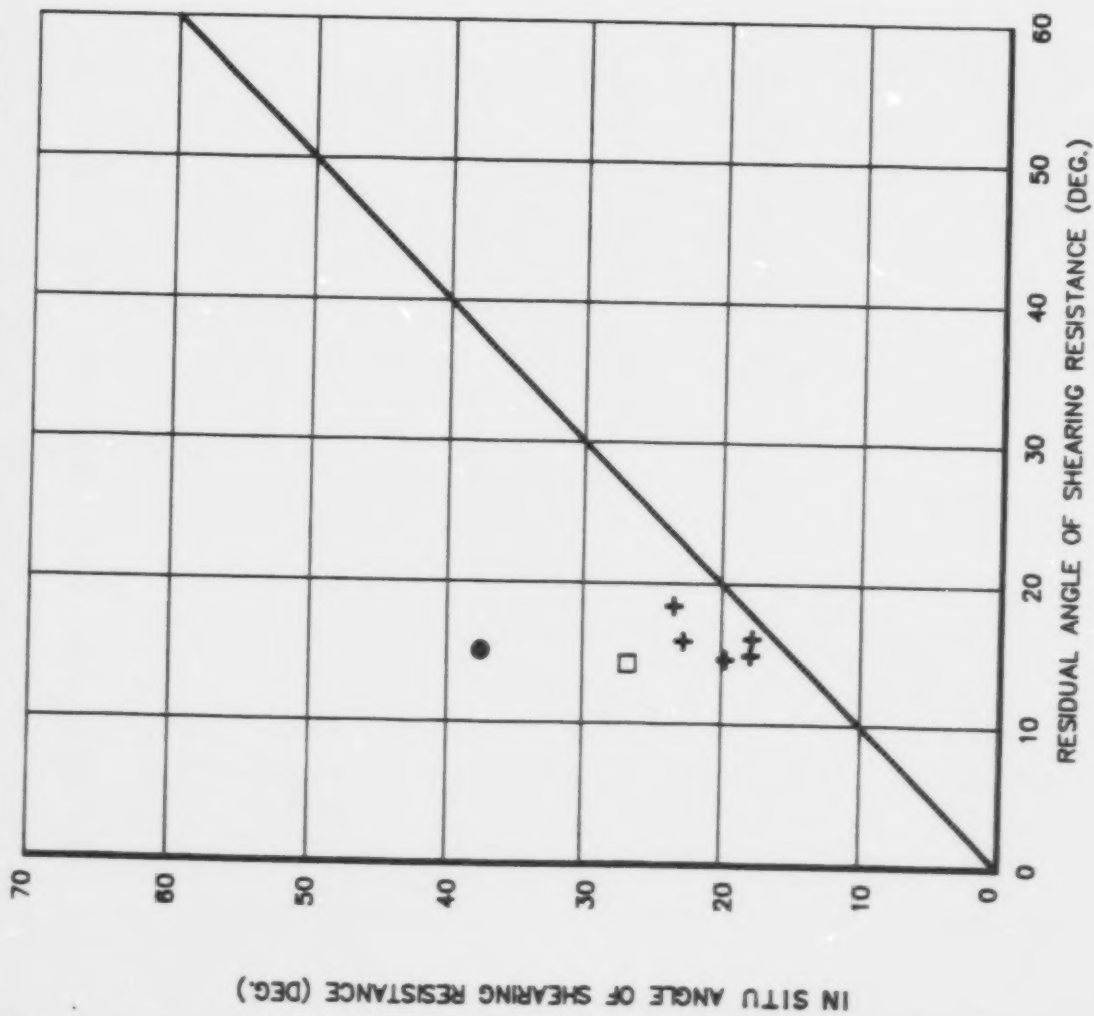
PLATE B-190



SHEAR STRENGTH - IN SITU
SEAM R14

REFERENCE ELEVATION AT SPILLWAY $\zeta = 1099.8 \text{ m}$

PLATE B-191



LEGEND:

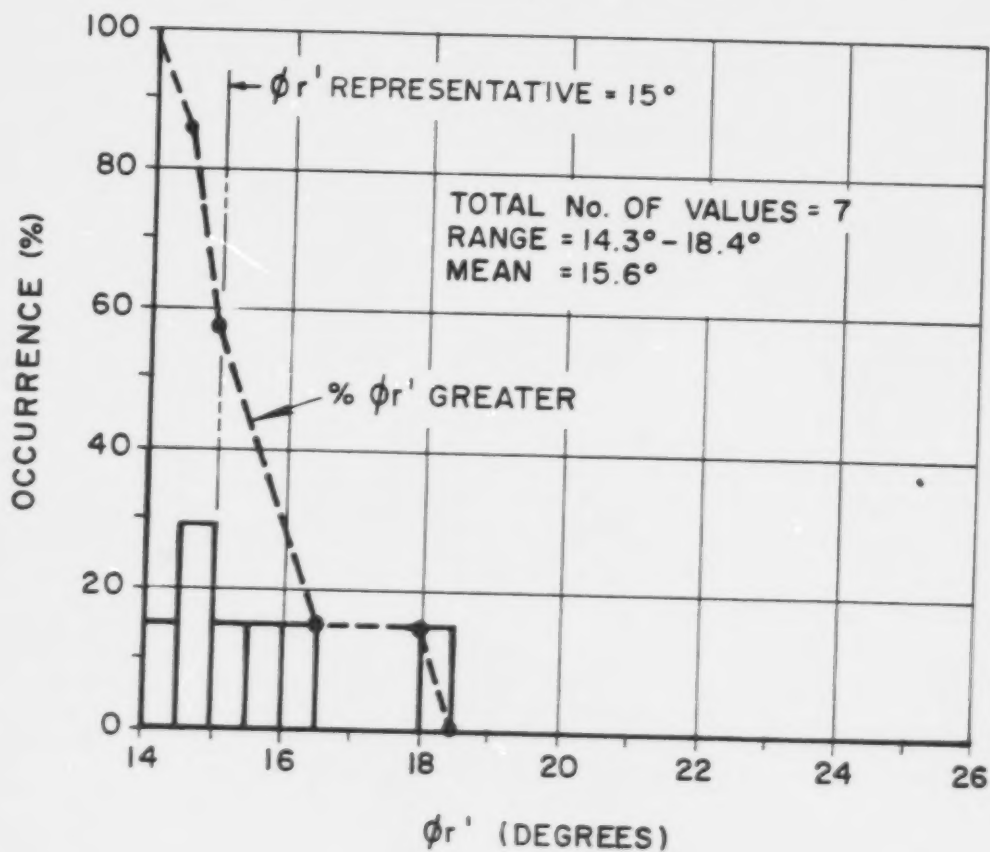
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



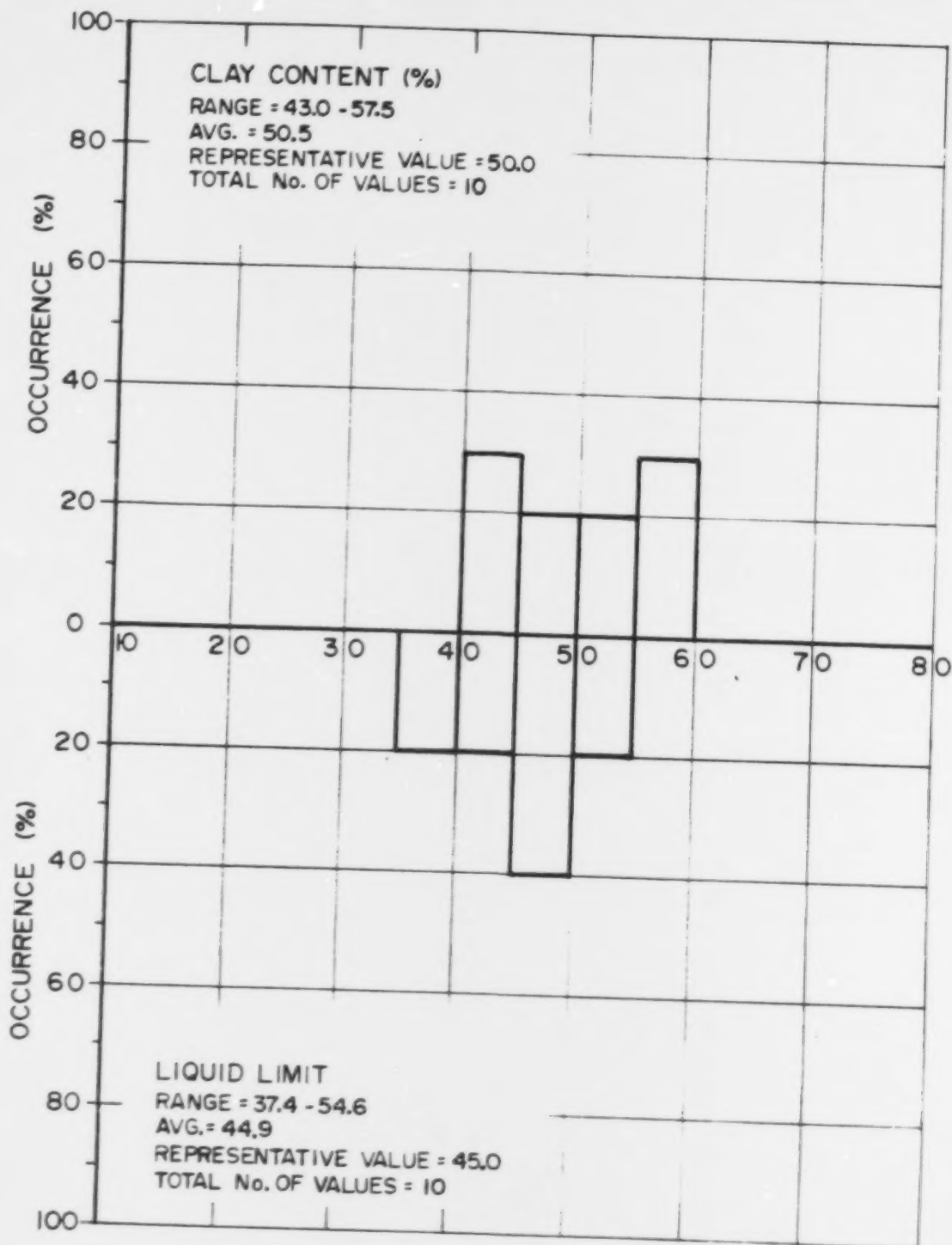
ϕ' in situ vs ϕ'
SEAM R14

PLATE B-192

IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO. R14
REFERENCE ELEVATION AT SPILLWAY $\phi' = 1099.8$ m



HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM NO. R14
 REFERENCE ELEVATION AT SPILLWAY $\phi = 1099.8\text{m}$



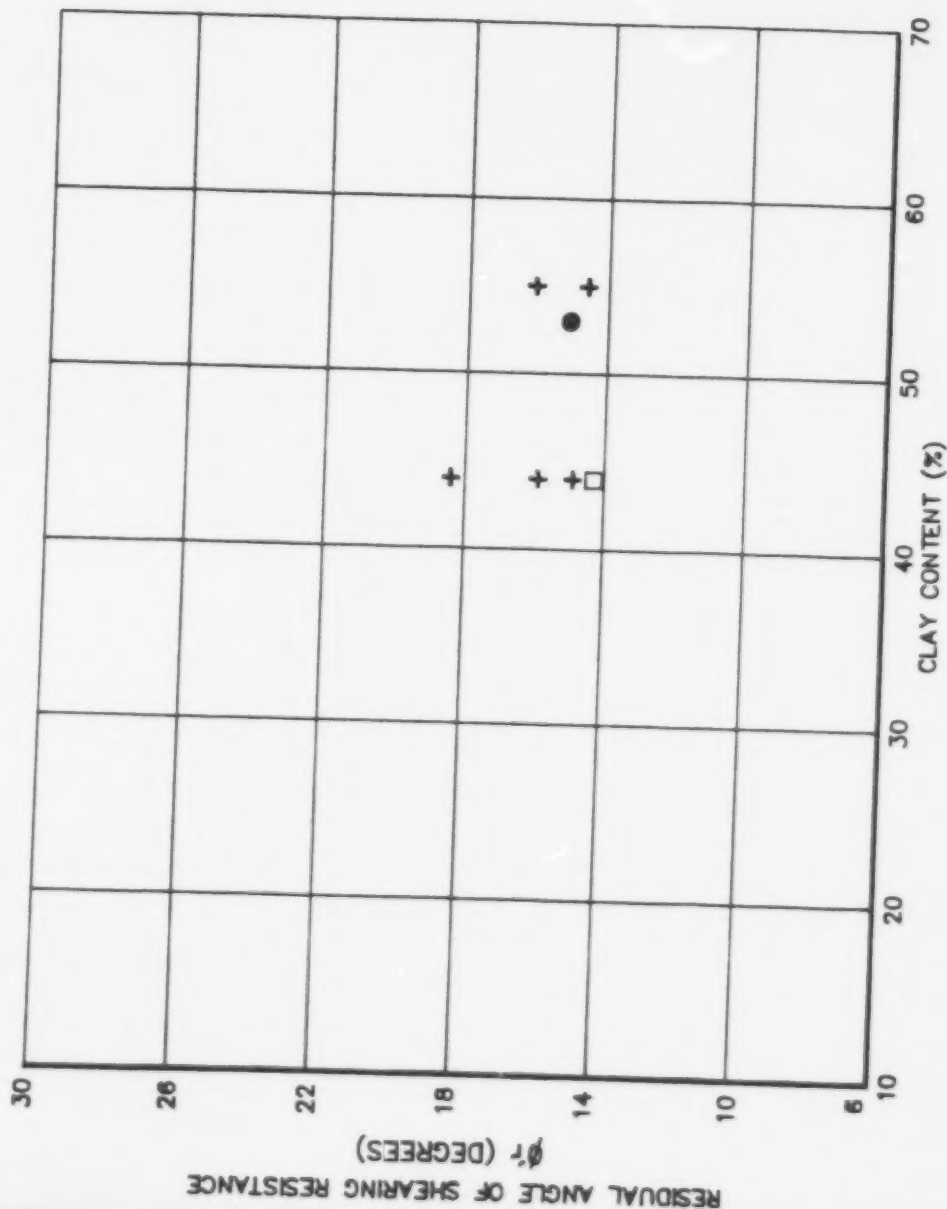
HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM NO. R14

REFERENCE ELEVATION AT SPILLWAY ζ = 1099.8m

ADCO INCORPORATED
 OLDMAN RIVER DAM

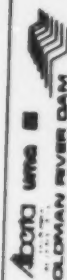
HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM R14

PLATE B-194



LEGEND:

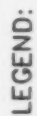
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs CLAY CONTENT
SEAM R14

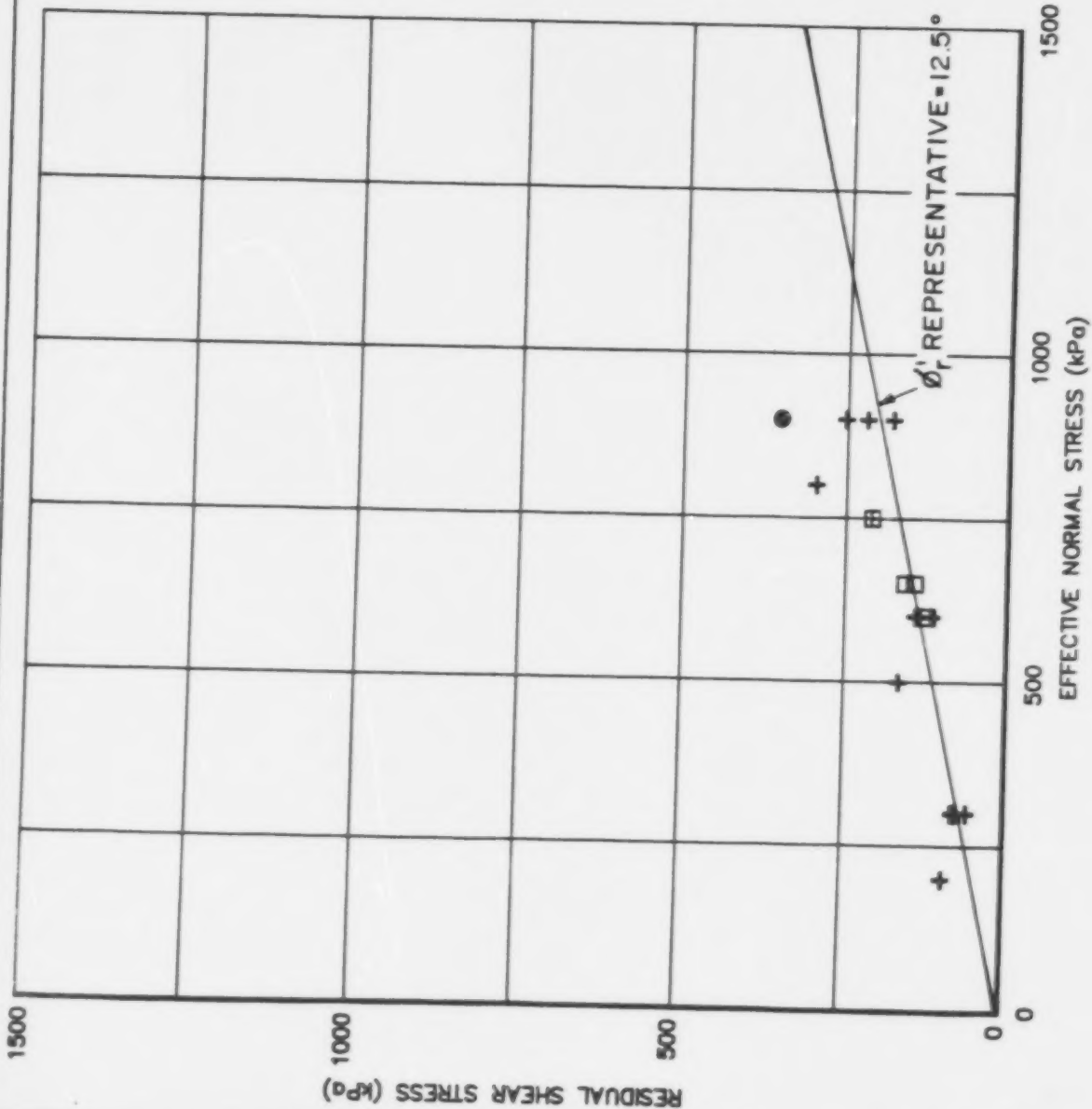
RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM NO. R14
REFERENCE ELEVATION AT SPILLWAY $\phi = 1099.8$ m

PLATE B-195



- | | | |
|---|---|---|
| ● | - | INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST |
| □ | - | SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST |
| + | - | SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH, 10 cm x 10 cm DIRECT SHEAR
TEST. |

SEAM NO. R14
REFERENCE ELEVATION AT SPILLWAY $\phi = 1099.8$ m



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
49.2	57.0
45.9	53.0
45.7	62.0
44.3	56.0
-	-
45.7	51.0
46.0	42.2
41.3	48.5
47.4	53.0
41.3	49.0
46.0	54.0
47.0	48.0
43.9	45.0
45.5	-
51.0	60.0
-	51.1
-	-
-	41.0
48.5	60.0
39.2	44.0
-	-
REPRESENTATIVE VALUES	
50.0	60.0

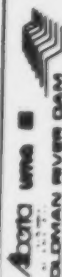
500

1000

1500

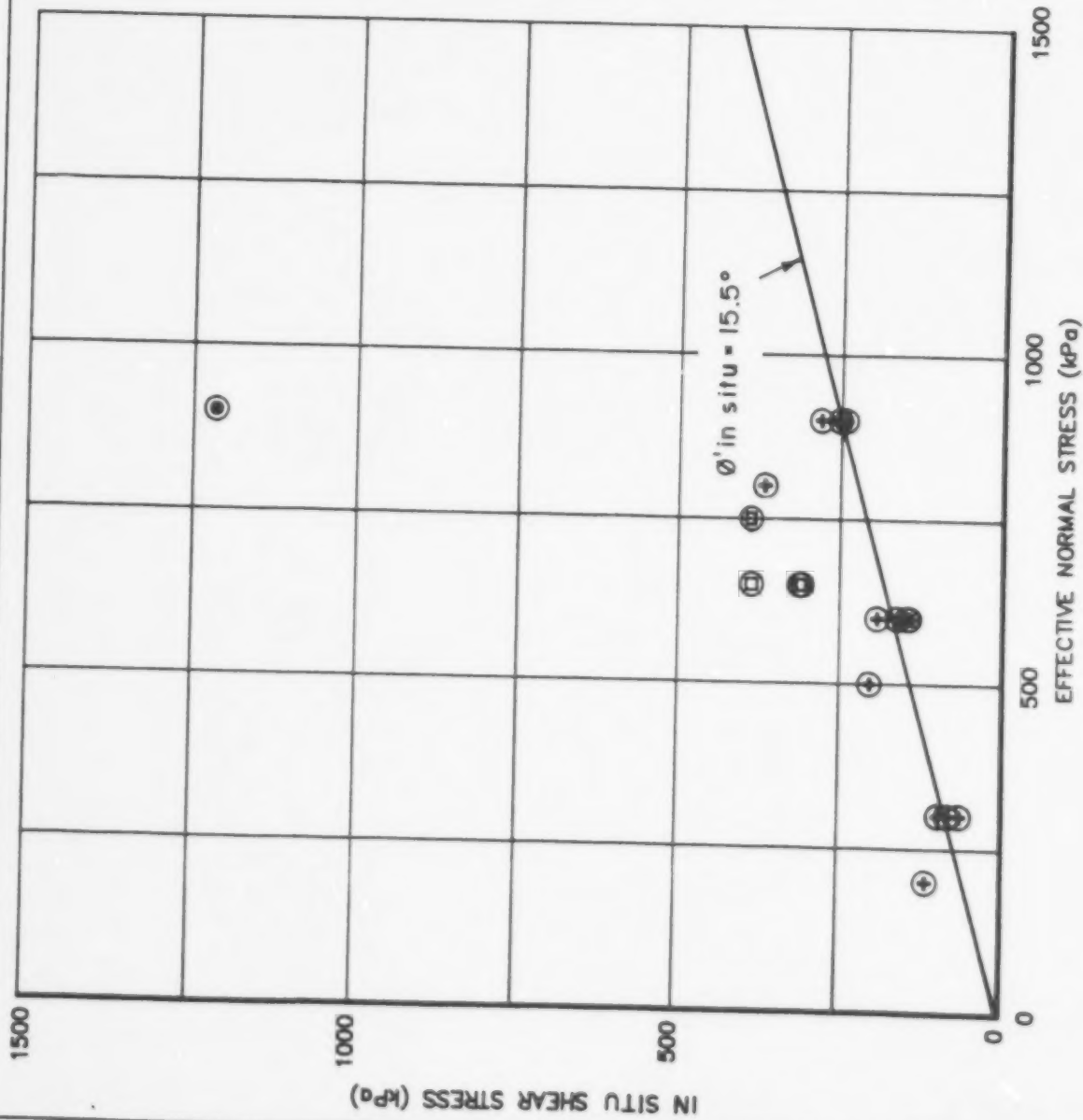
SHEAR STRENGTH - RESIDUAL SEAM NO. R16

REFERENCE ELEVATION AT SPILLWAY $\phi = 1105.0$ m



SHEAR STRENGTH - RESIDUAL SEAM R16

PLATE B-197



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

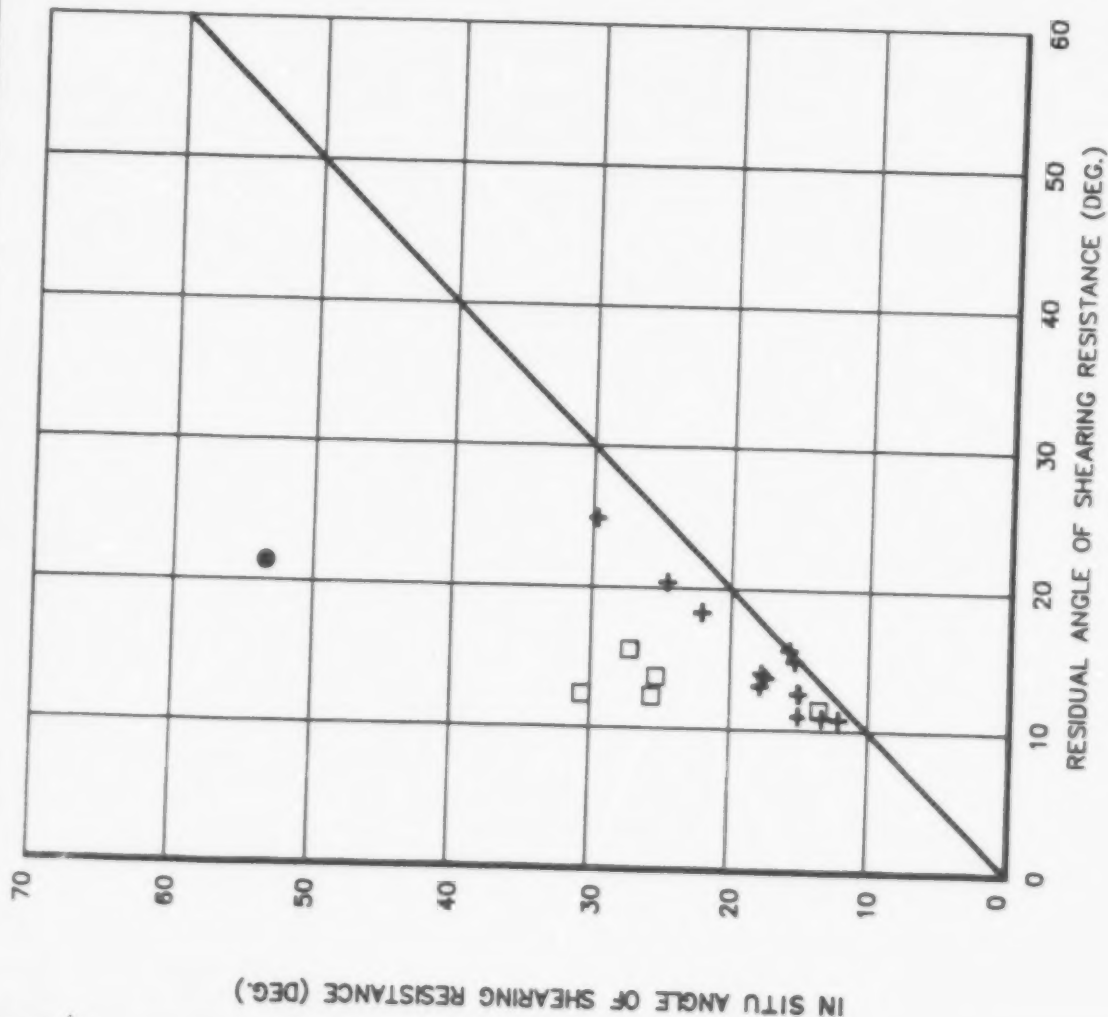


DEPARTMENT OF WATER AFFAIRS AND FORESTRY
SOUTH AFRICA

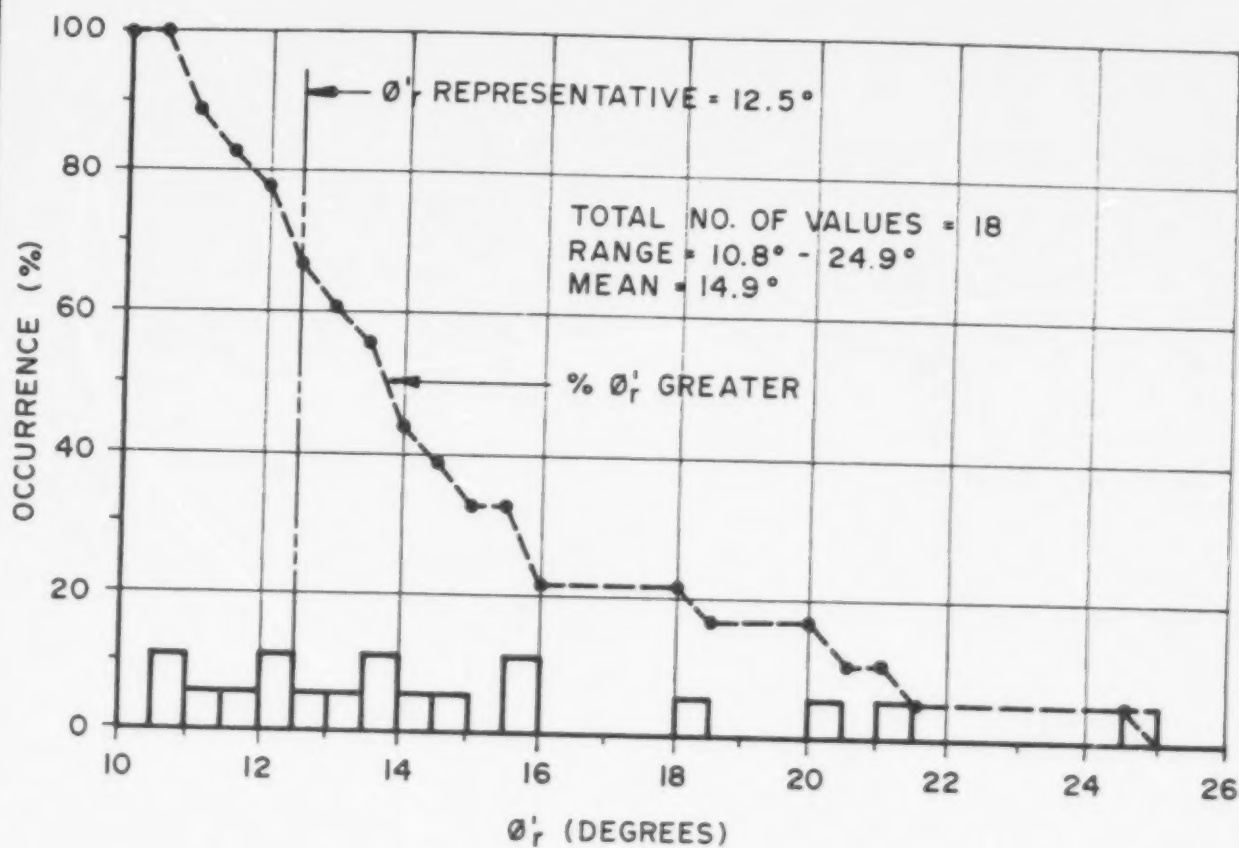
SHEAR STRENGTH - IN SITU
SEAM R16

PLATE B-198

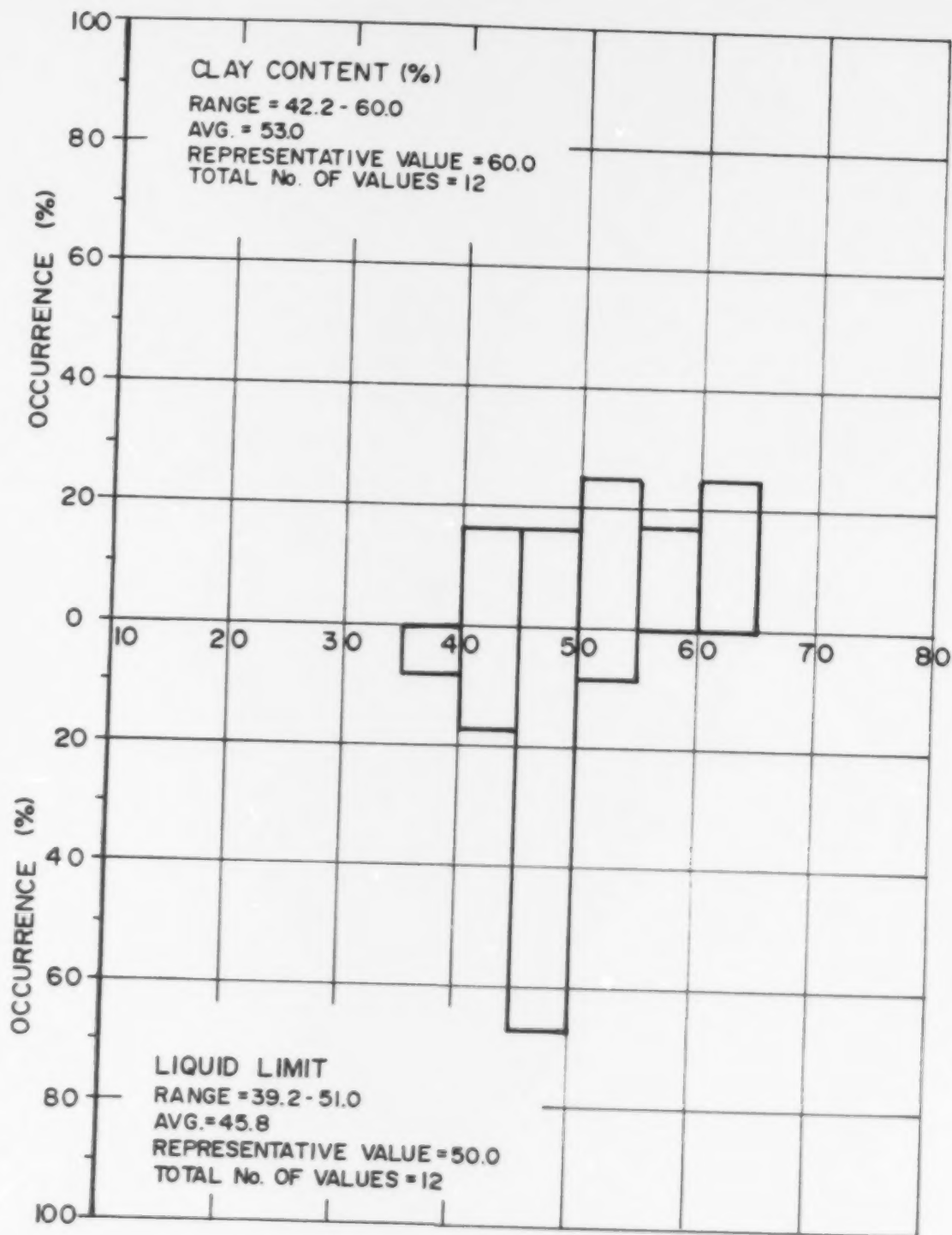
SHEAR STRENGTH - IN SITU
SEAM NO. R16
REFERENCE ELEVATION AT SPILLWAY $\phi = 1105.0$ m



IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO. R16
REFERENCE ELEVATION AT SPILLWAY $\phi = 1105.0$ m

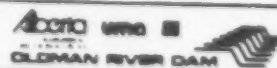


HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM NO. R16
 REFERENCE ELEVATION AT SPILLWAY $\phi = 1105.0$ m



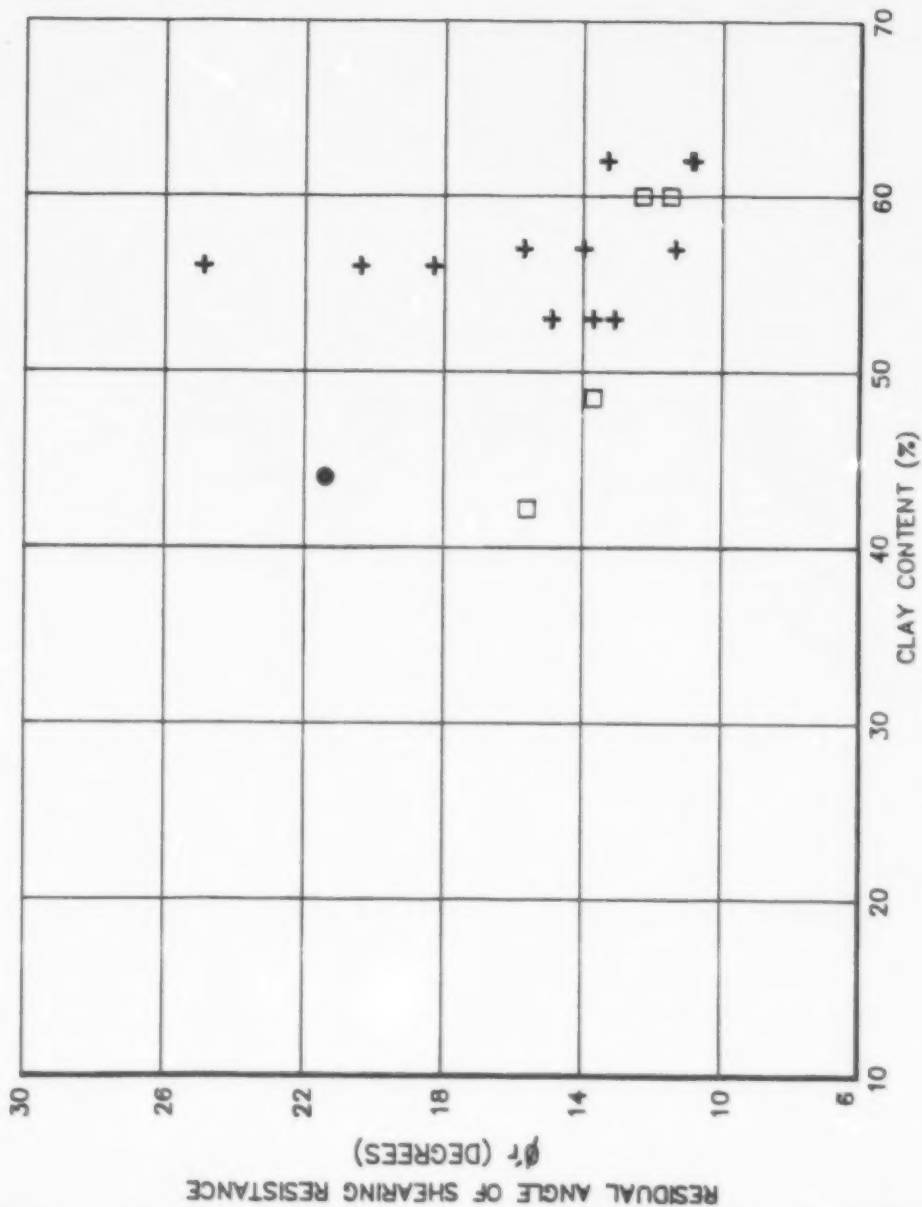
HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM No. R16

REFERENCE ELEVATION AT SPILLWAY ζ = 1105m

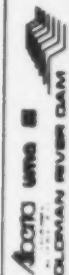


HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM R16

PLATE B-201

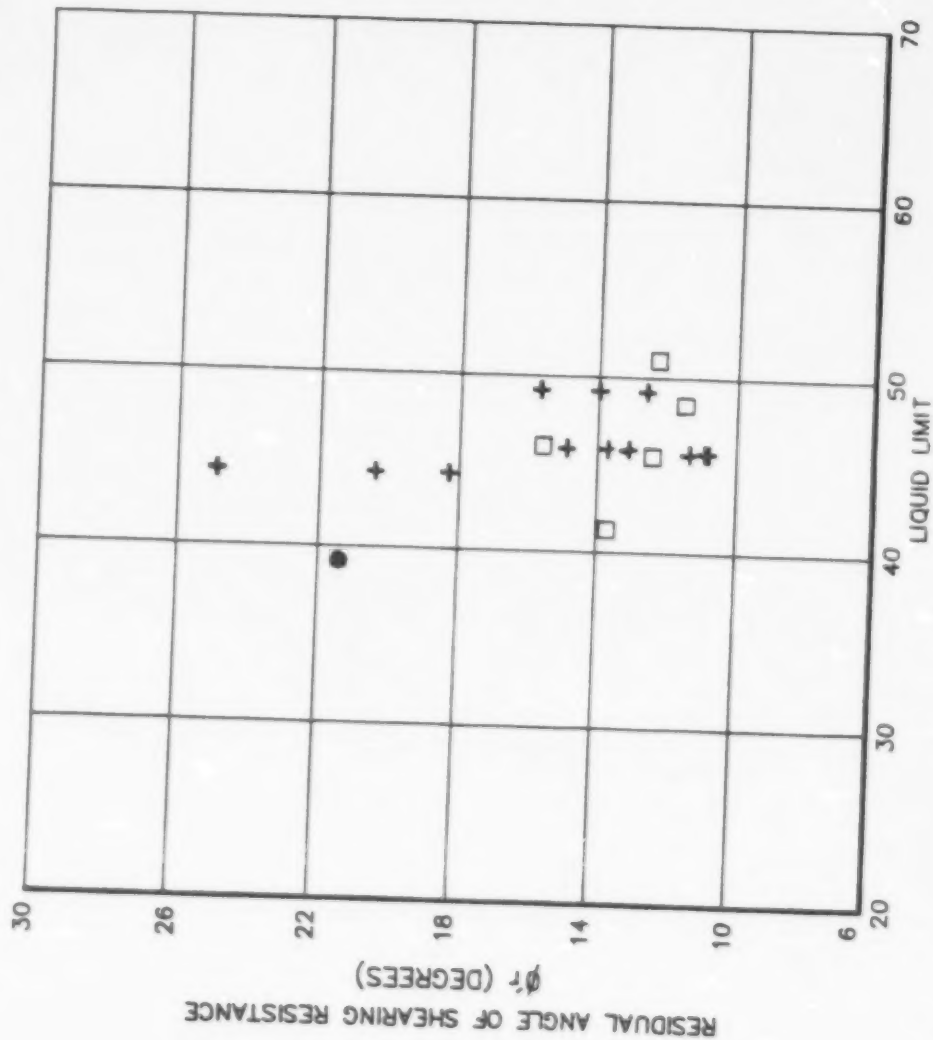


RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM No. R16
REFERENCE ELEVATION AT SPILLWAY $\phi = 1105.0$ m



ϕ_r vs CLAY CONTENT
SEAM No. R16

PLATE B-202



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- +

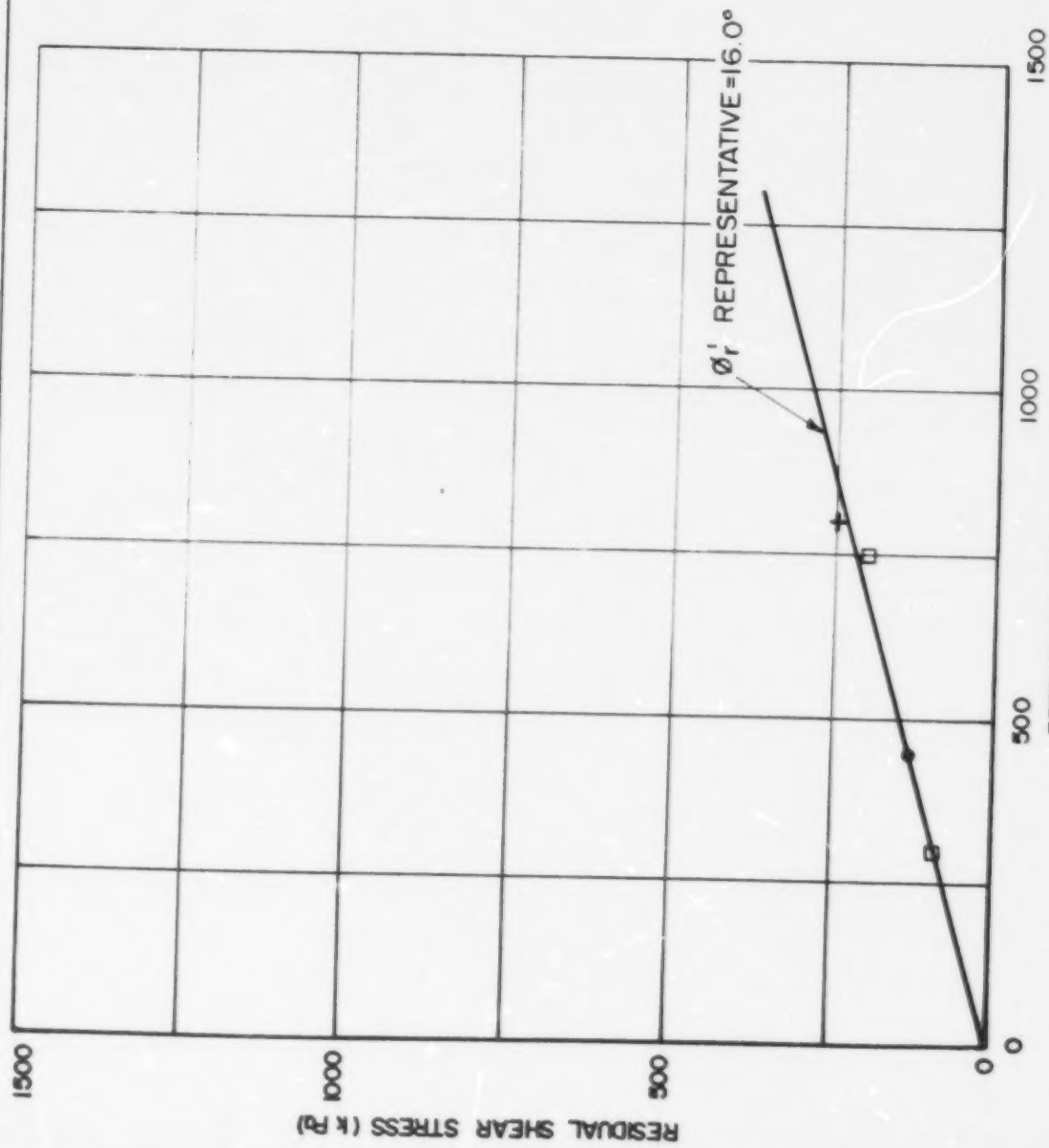
SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs LIQUID LIMIT
SEAM No. R16

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM No. R16
REFERENCE ELEVATION AT SPILLWAY $\phi = 1105.0$ m

PLATE B-203



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
38.0	40.0
52.0	49.0
44.0	41.0
43.1	56.0
-	-
REPRESENTATIVE VALUES	
47.0	48.0

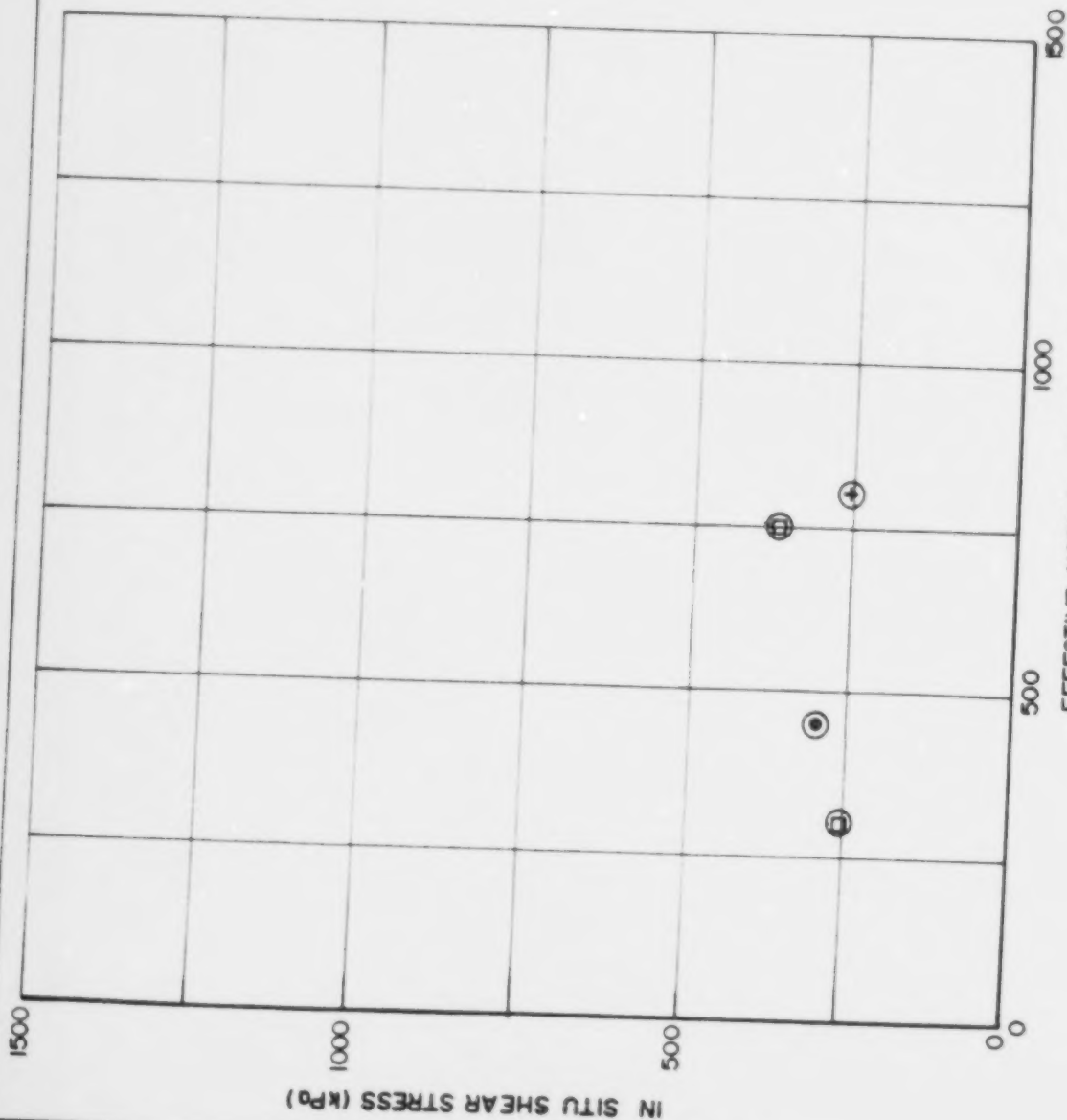


Abeng Group
CONSULTANTS
OLDMAN RIVER DAM

SHEAR STRENGTH - RESIDUAL
SEAM No. R17

PLATE B-204

EFFECTIVE NORMAL STRESS (kPa)
SHEAR STRENGTH - RESIDUAL
SEAM No. R17
REFERENCE ELEVATION AT SPILLWAY $\bar{C}$ = 1107.7m



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
8 cm x 8 cm DIRECT SHEAR TEST
- ⊗ - BEAM SAMPLE OBTAINED FROM DRILLHOLE, 8 cm x 8 cm DIRECT SHEAR TEST
- ⊕ - BEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



SHEAR STRENGTH - IN SITU
SEAM No. R17

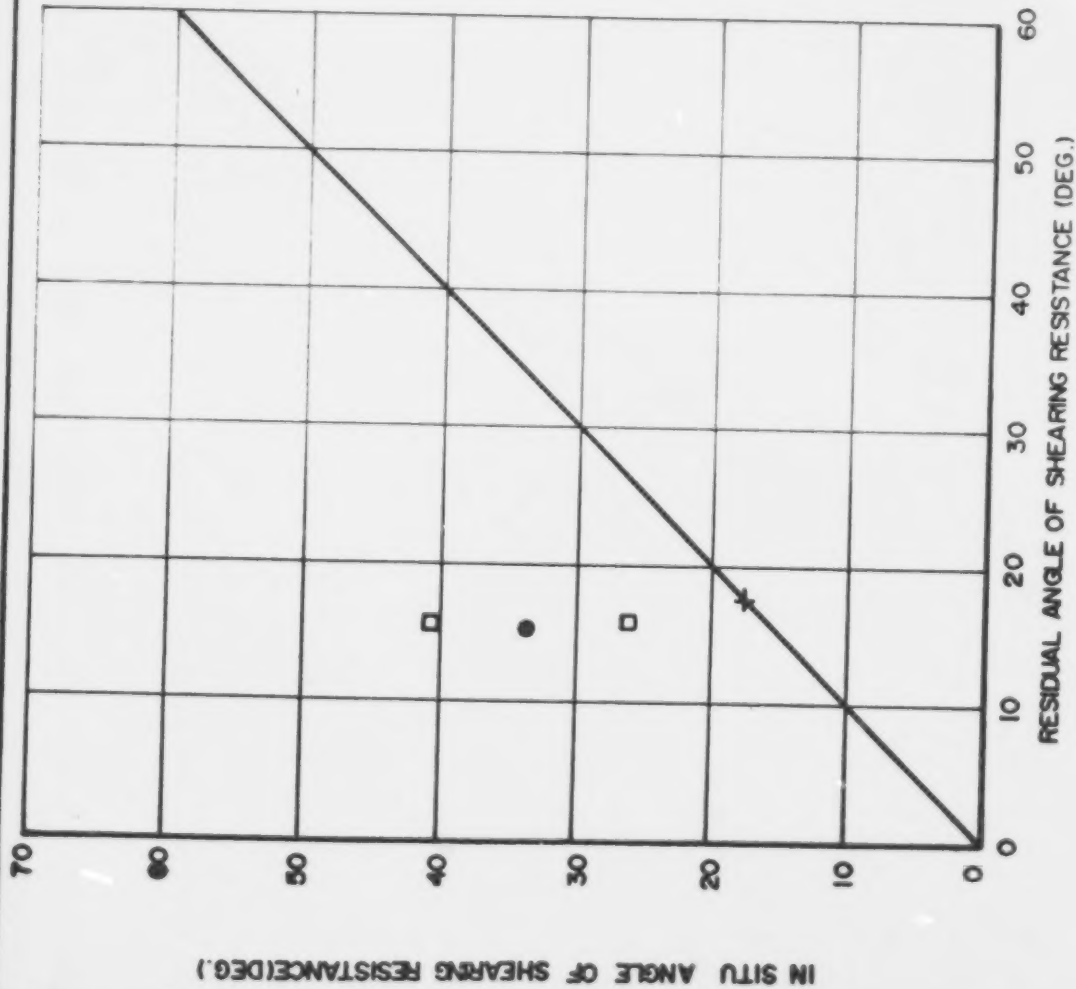
PLATE B-205

EFFECTIVE NORMAL STRESS (kPa)

SHEAR STRENGTH - IN SITU

SEAM No. R17

REFERENCE ELEVATION AT SPILLWAY $\zeta = 1107.7\text{m}$



LEGEND:

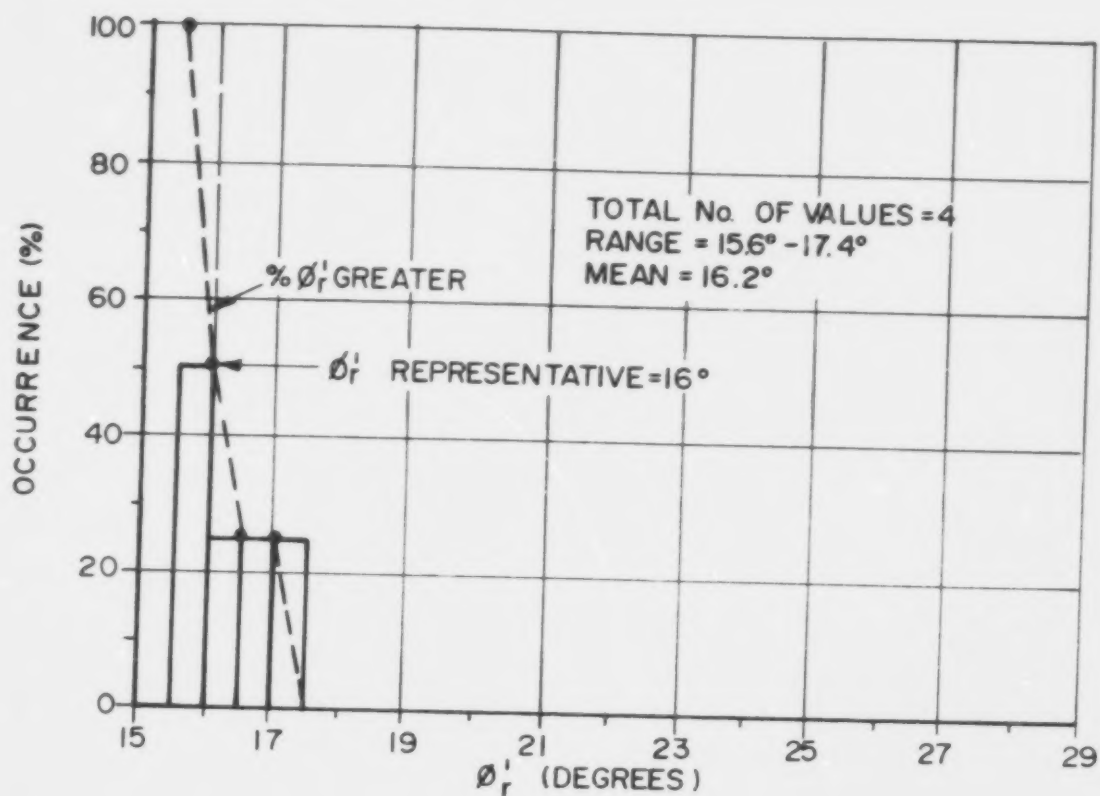
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



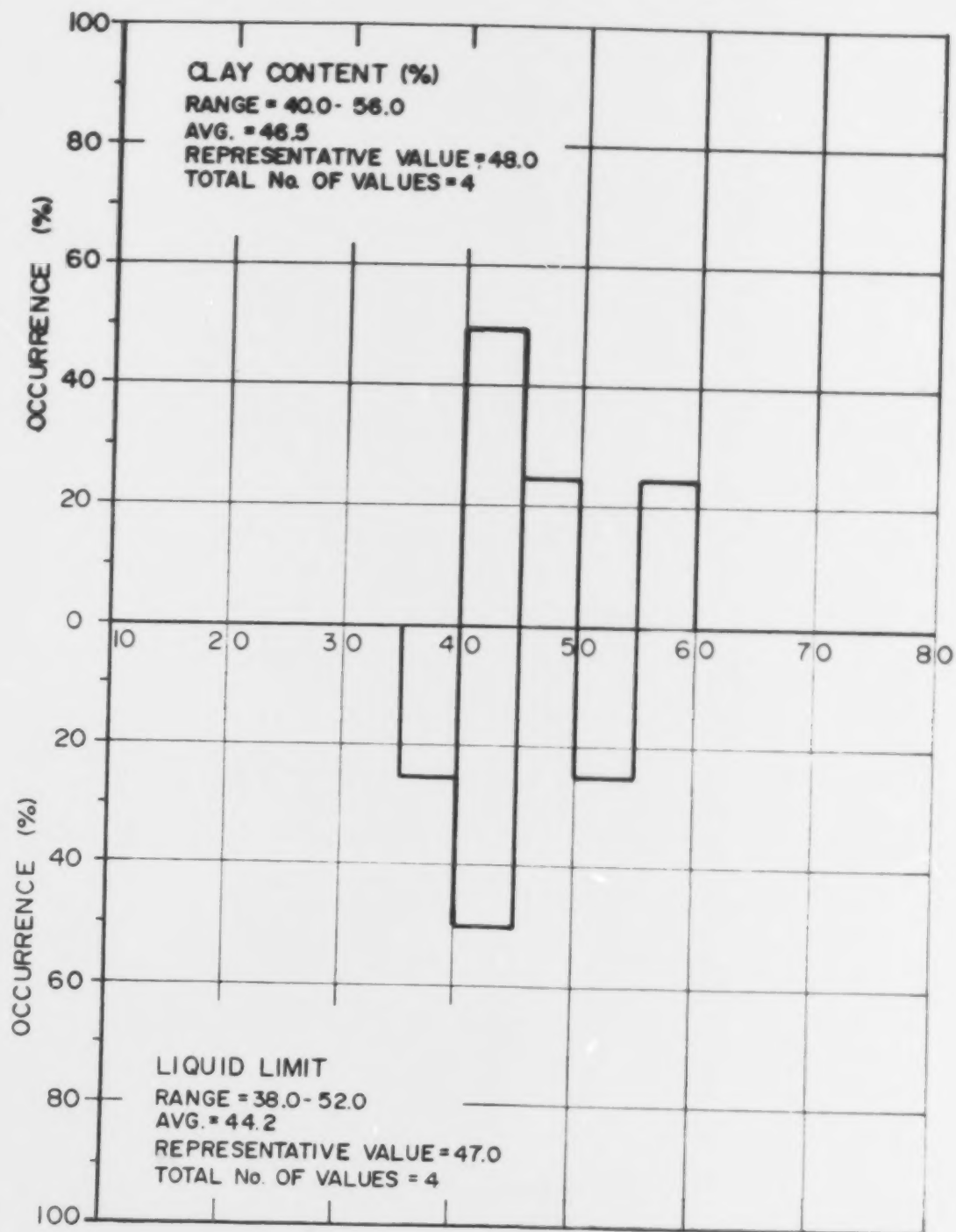
ϕ_r - IN SITU VS ϕ_s'
SEAM R17

IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO. R 17
REFERENCE ELEVATION AT SPILLWAY $\phi = 1107.7m$

PLATE B-206



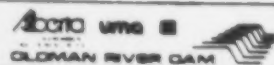
HISTOGRAM OF RESIDUAL SHEAR STRENGTH
SEAM No. R17
REFERENCE ELEVATION AT SPILLWAY $\zeta = 1107.7\text{m}$



HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT

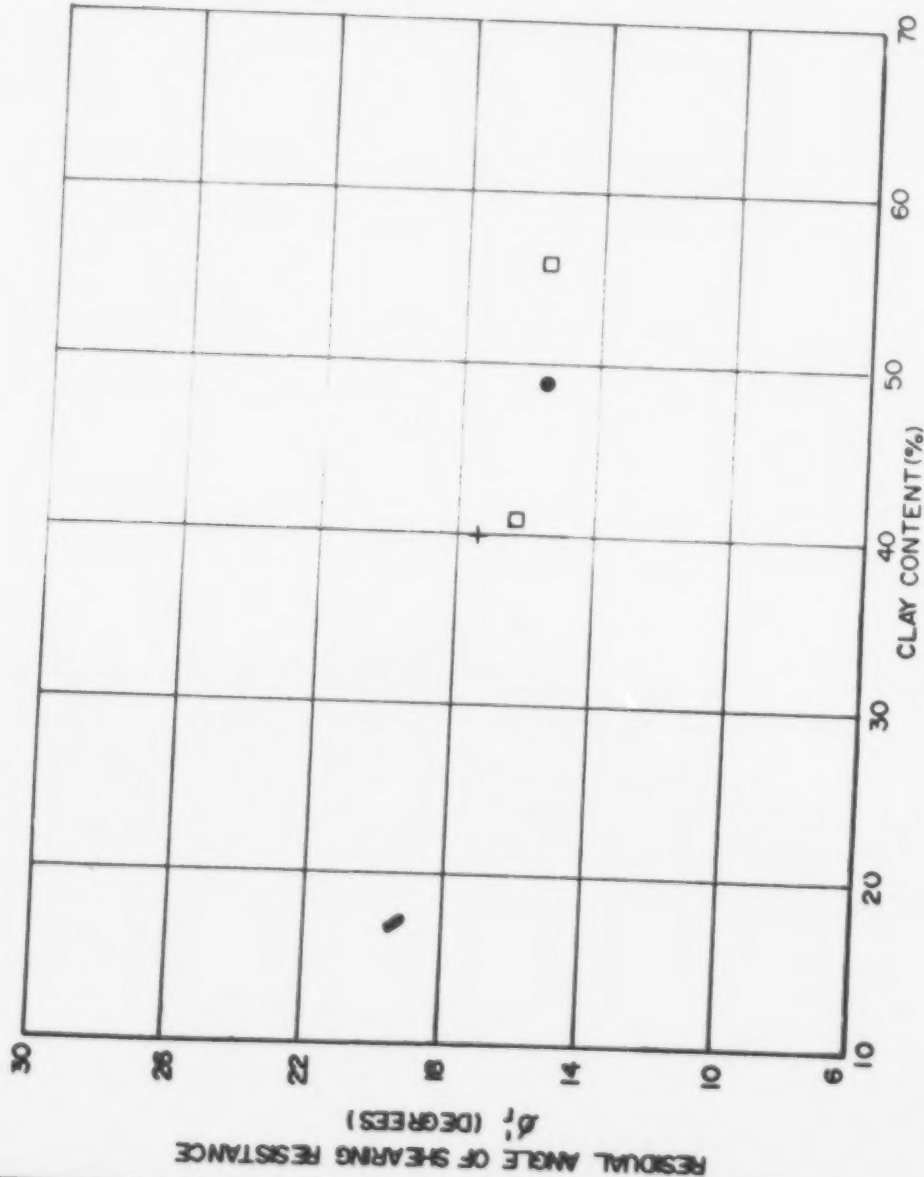
SEAM No. R17

REFERENCE ELEVATION AT SPILLWAY $\zeta = 1107.7\text{m}$



HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM No. R17

PLATE B-208



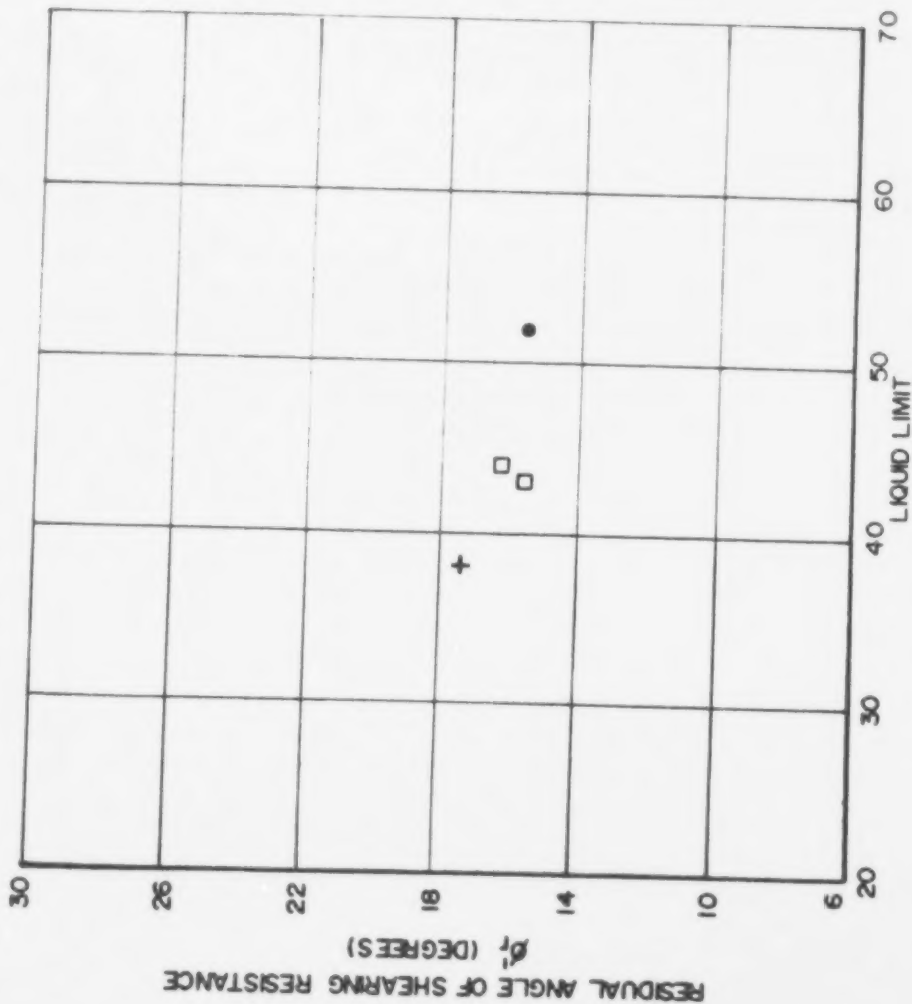
LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- +
- SEAM SAMPLE OBTAINED FROM DRILL HOLE 5 cm x 5 cm DIRECT SHEAR TEST
- SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



61' VS CLAY CONTENT
SEAM No. R17

RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM No. R17
REFERENCE ELEVATION AT SPILLWAY $\phi = 1107.7m$



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING 5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE 5 cm x 5 cm DIRECT SHEAR TEST
- +

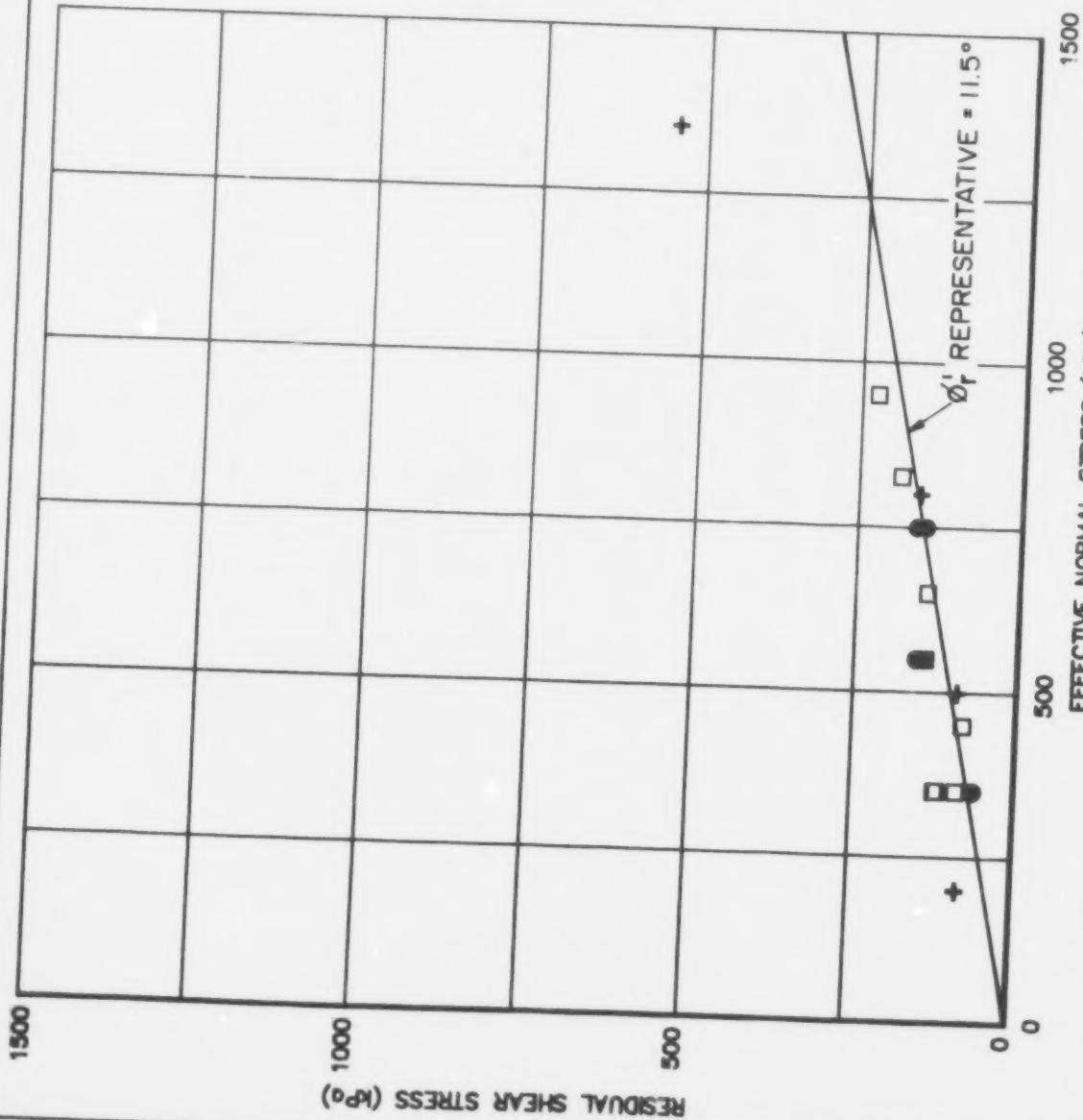
SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



ϕ_r vs LIQUID LIMIT
SEAM No. R17

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM No. R17
REFERENCE ELEVATION AT SPILLWAY $\zeta = 1107.7m$

PLATE B-210



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

LL	C%
46.0	38.0
54.2	60.0
-	42.6
47.3	-
51.1	49.0
45.0	59.0
49.0	65.0
45.8	44.0
56.0	61.0
48.5	-
46.6	35.0
41.8	-
-	34.4
REPRESENTATIVE VALUES	
45.0	50.0

EFFECTIVE NORMAL STRESS (kPa)

SHEAR STRENGTH - RESIDUAL
SEAM NO. R18

REFERENCE ELEVATION AT SPILLWAY $\phi = 1115.0$ m

1500

500

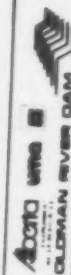
1000

1500

EFFECTIVE NORMAL STRESS (kPa)

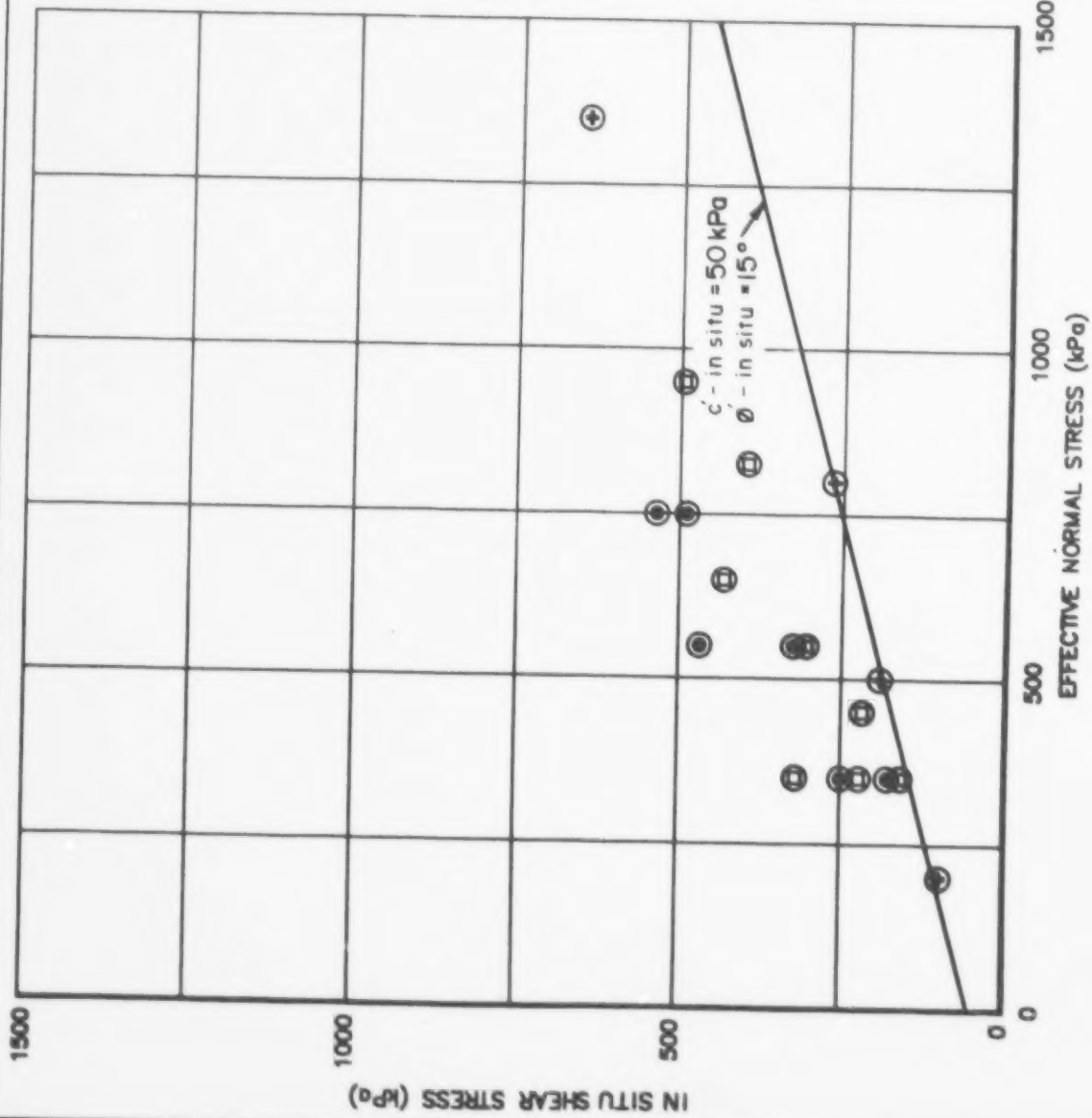
SHEAR STRENGTH - RESIDUAL
SEAM NO. R18

REFERENCE ELEVATION AT SPILLWAY $\phi = 1115.0$ m



SHEAR STRENGTH - RESIDUAL
SEAM R18

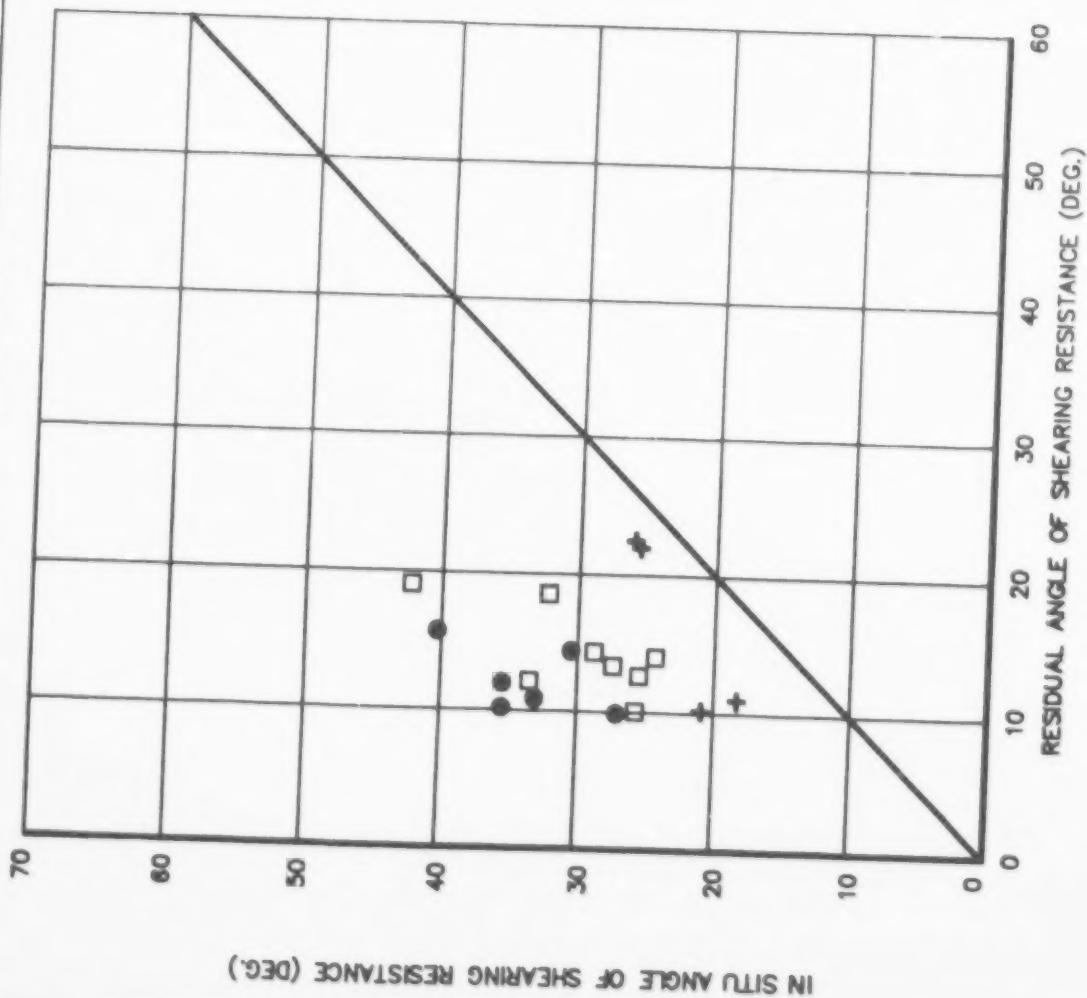
PLATE B-211



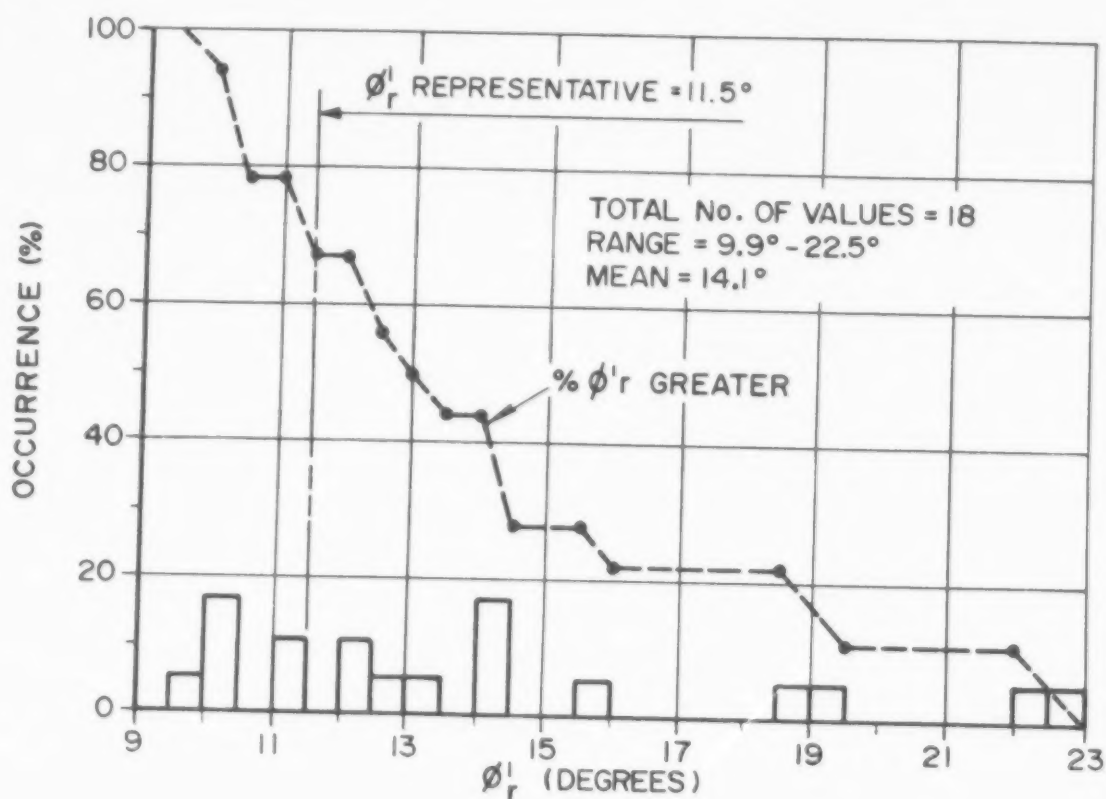
SHEAR STRENGTH - IN SITU
 SEAM NO. R18
 REFERENCE ELEVATION AT SPILLWAY $\phi = 1115.0 \text{ m}$



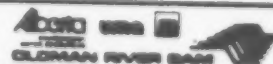
SHEAR STRENGTH - IN SITU
 SEAM R18



IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
SEAM NO. R18
REFERENCE ELEVATION AT SPILLWAY $\phi = 1115.0$ m

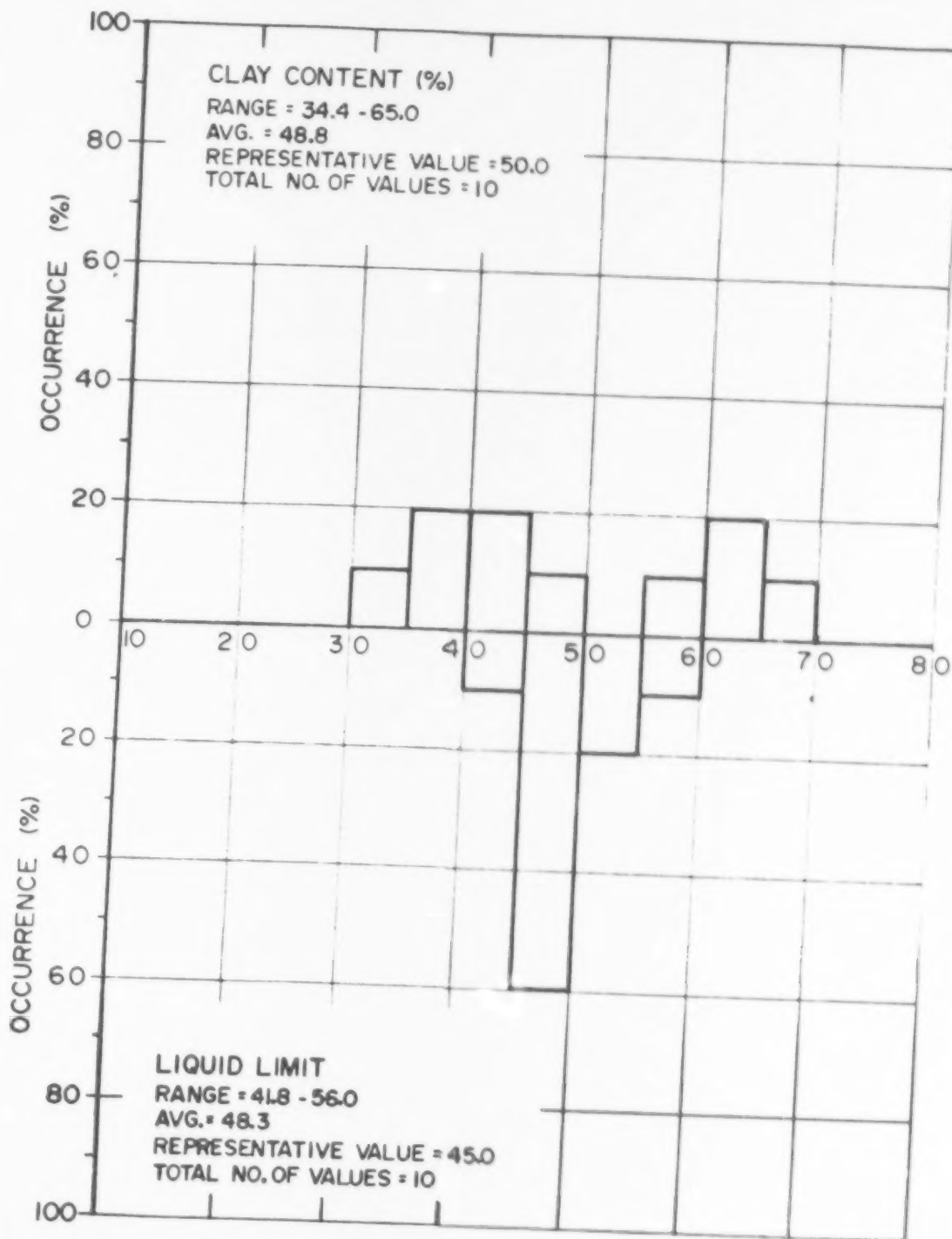


HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM NO. R18
 REFERENCE ELEVATION AT SPILLWAY ζ = 1115 m



HISTOGRAM OF ϕ_r
 SEAM R18

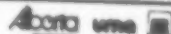
PLATE B-214



HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT

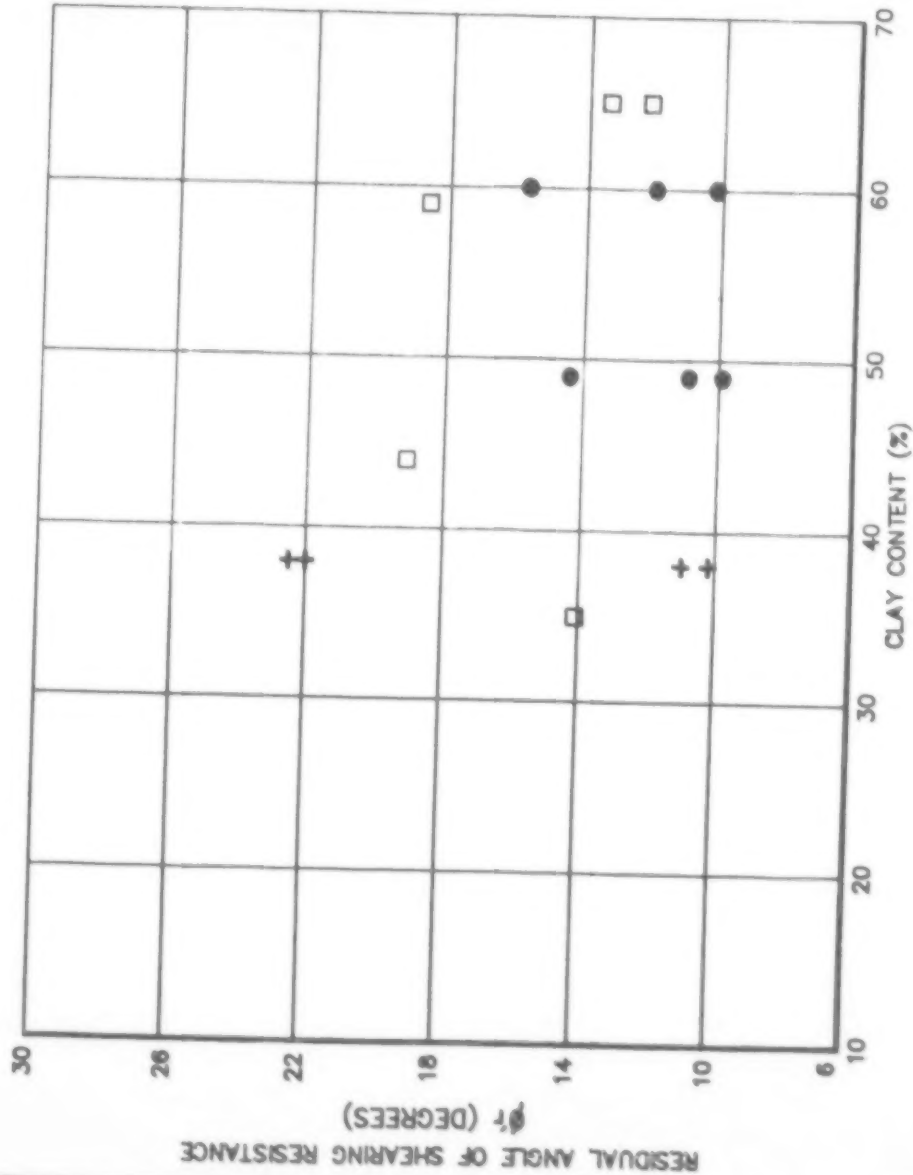
SEAM NO. R18

REFERENCE ELEVATION AT SPILLWAY $\zeta = 1115m$

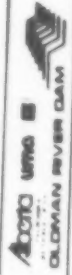
 MINISTRY OF WATER RESOURCES GOVERNMENT OF INDIA	
HISTOGRAM OF CLAY CONTENT AND LIQUID LIMIT SEAM R18	
PLATE B-215	

LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED
ALONG BEDDING
- - 5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM DRILLHOLE
5 cm x 5 cm DIRECT SHEAR TEST
- + - SEAM SAMPLE OBTAINED FROM SHAFT OR
TRENCH, 10 cm x 10 cm DIRECT SHEAR
TEST.



RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
SEAM NO. R18
REFERENCE ELEVATION AT SPILLWAY $\phi = 1115.0$ m



VS CLAY CONTENT
SEAM R18

PLATE B-216



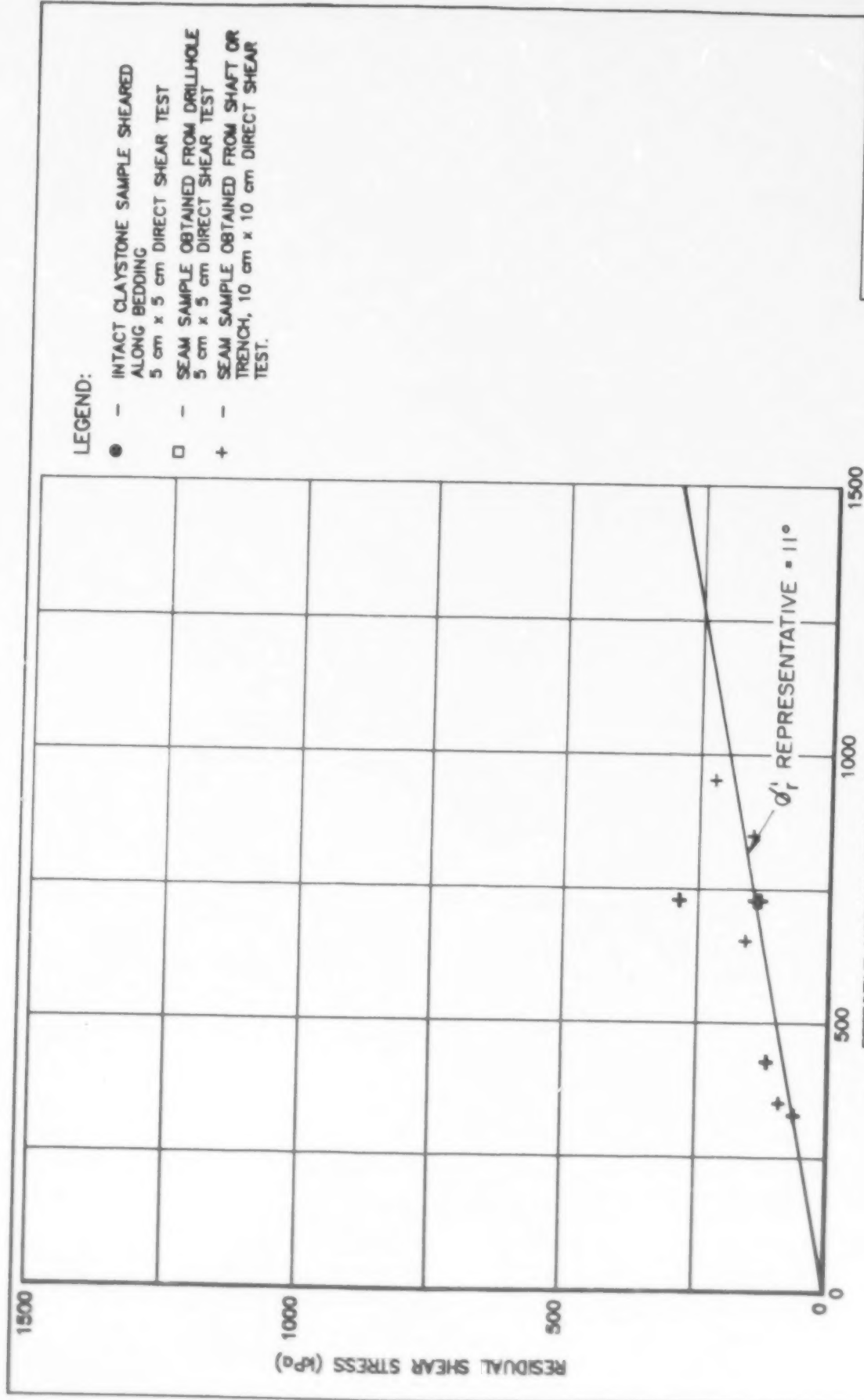
- | | |
|---|---|
| - | INTACT GLAYSTONE SAMPLE SHEARED ALONG BEDDING |
| □ | 5 cm x 5 cm DIRECT SHEAR TEST |
| - | SEAM SAMPLE OBTAINED FROM DRILLHOLE |
| + | 5 cm x 5 cm DIRECT SHEAR TEST |
| - | SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST. |

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
SEAM NO. R18
REFERENCE ELEVATION AT SPILLWAY $\zeta = 1115.0$ m

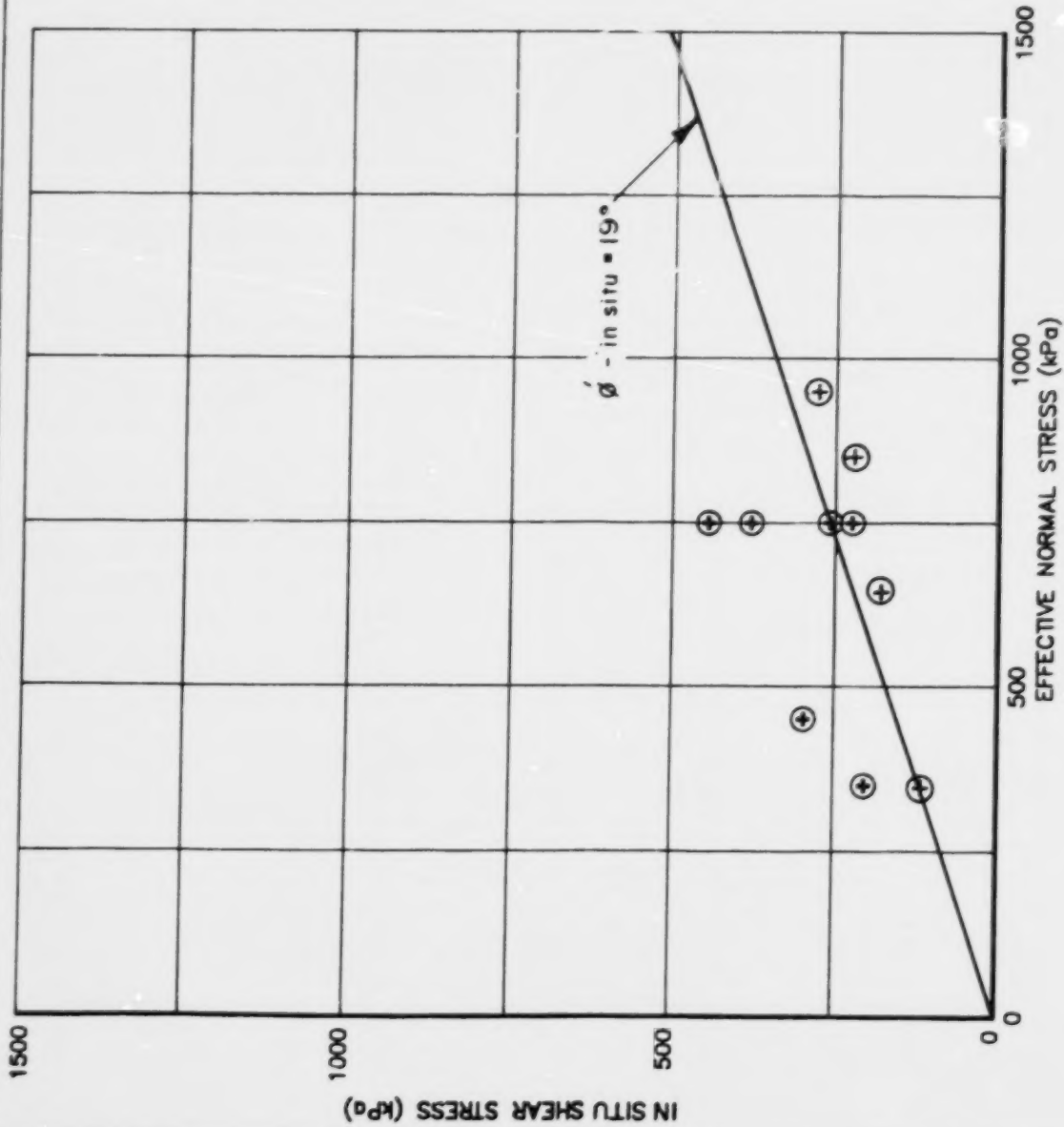


ϕ_r vs LIQUID LIMIT
SEAM R18

PLATE B-217



SHEAR STRENGTH - RESIDUAL
 UPSTREAM DIVERSION TUNNEL PORTAL
 SEAM NO. 2
 CORRESPONDING TO SEAM NO. R9
 REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m



LEGEND:

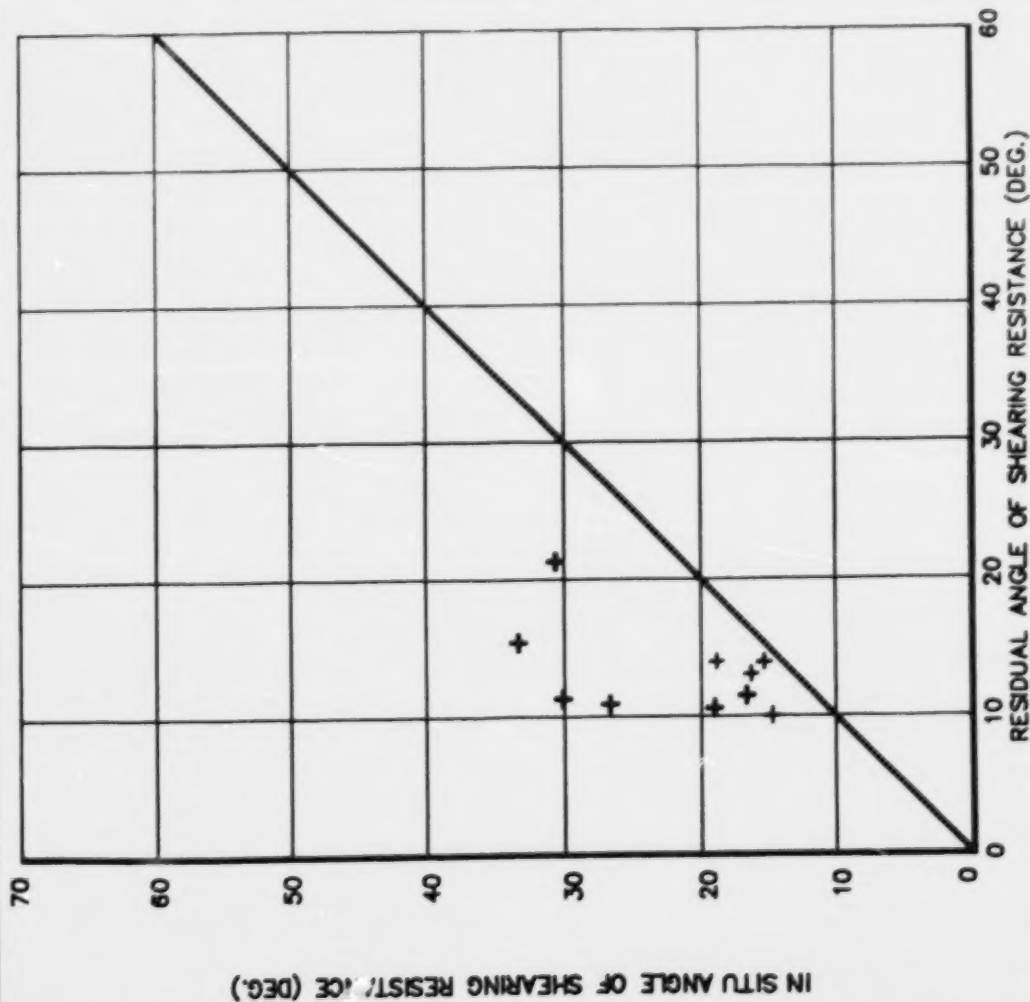
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.



SHEAR STRENGTH - IN SITU
SEAM 2

PLATE B-219

SHEAR STRENGTH - IN SITU
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM NO. 2
CORRESPONDING TO SEAM NO. R9
REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m



IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
UPSTREAM DIVERSION TUNNEL PORTAL

SEAM NO. 2

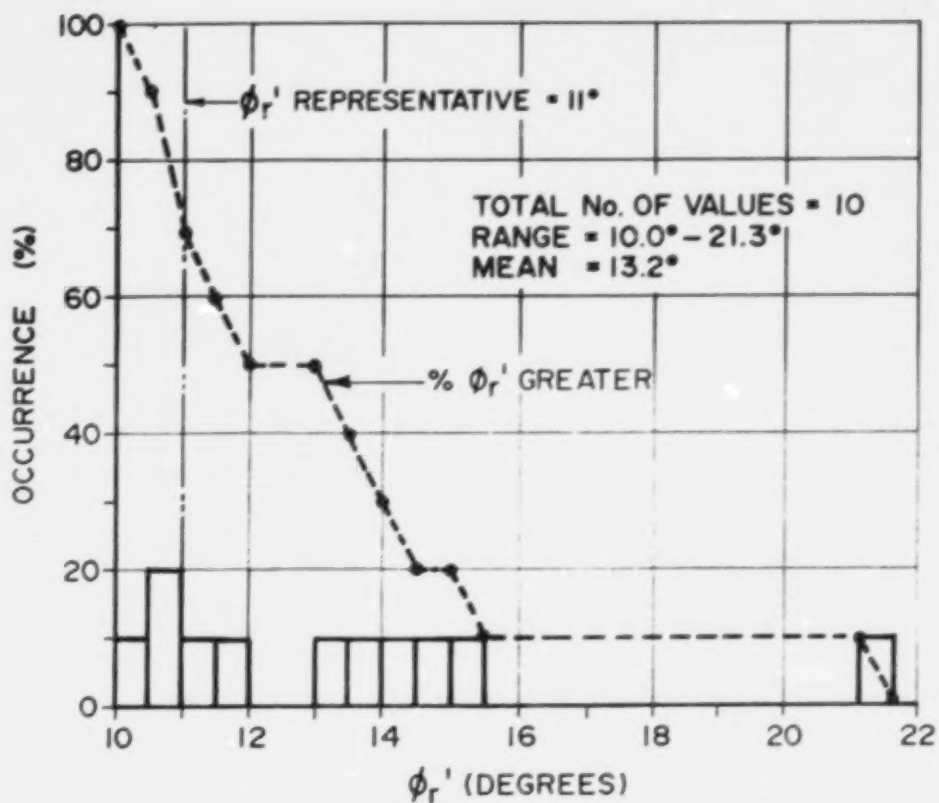
CORRESPONDING TO SEAM NO. R9

REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m

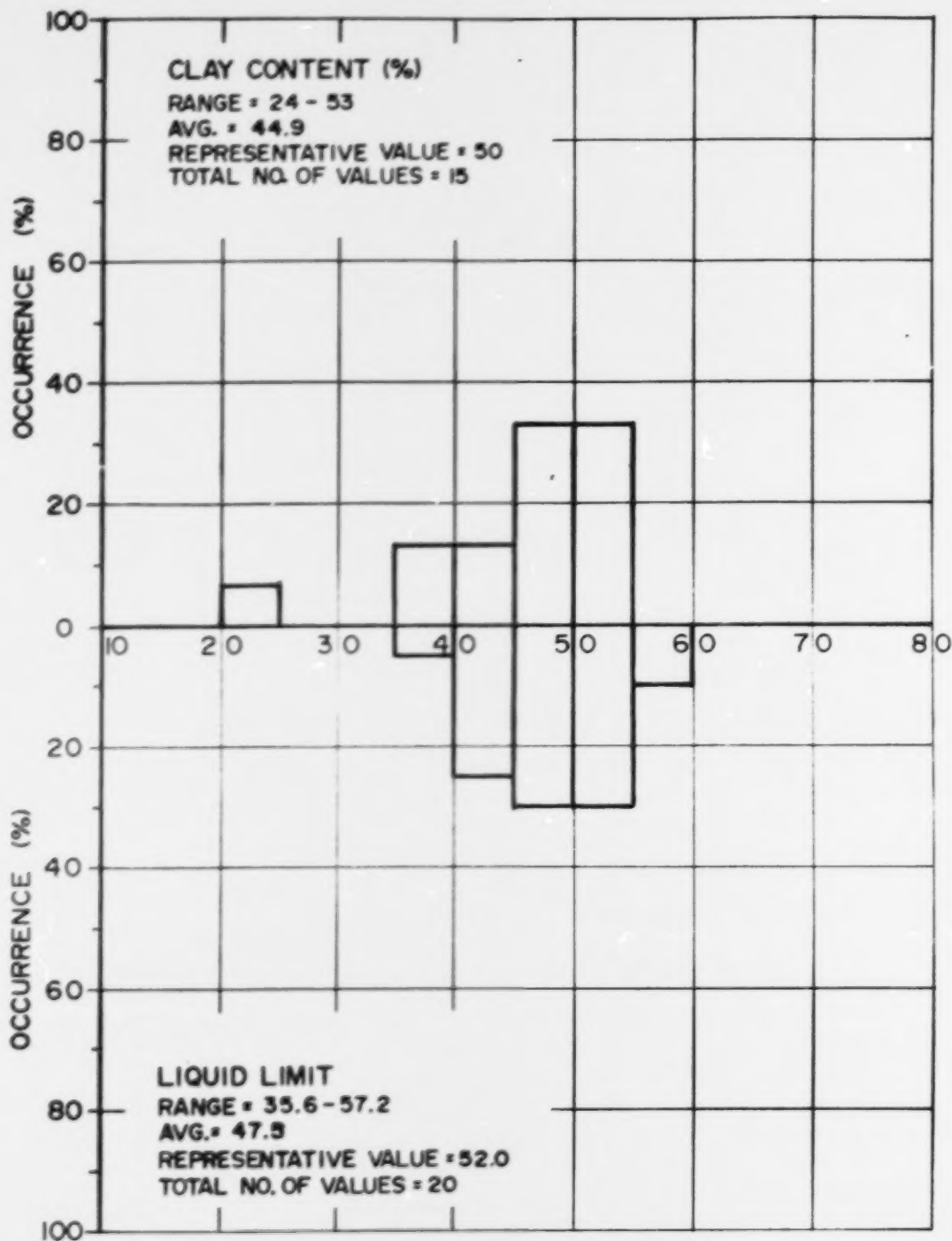


IN SITU VS ϕ_r
SEAM 2

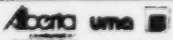
PLATE B-220

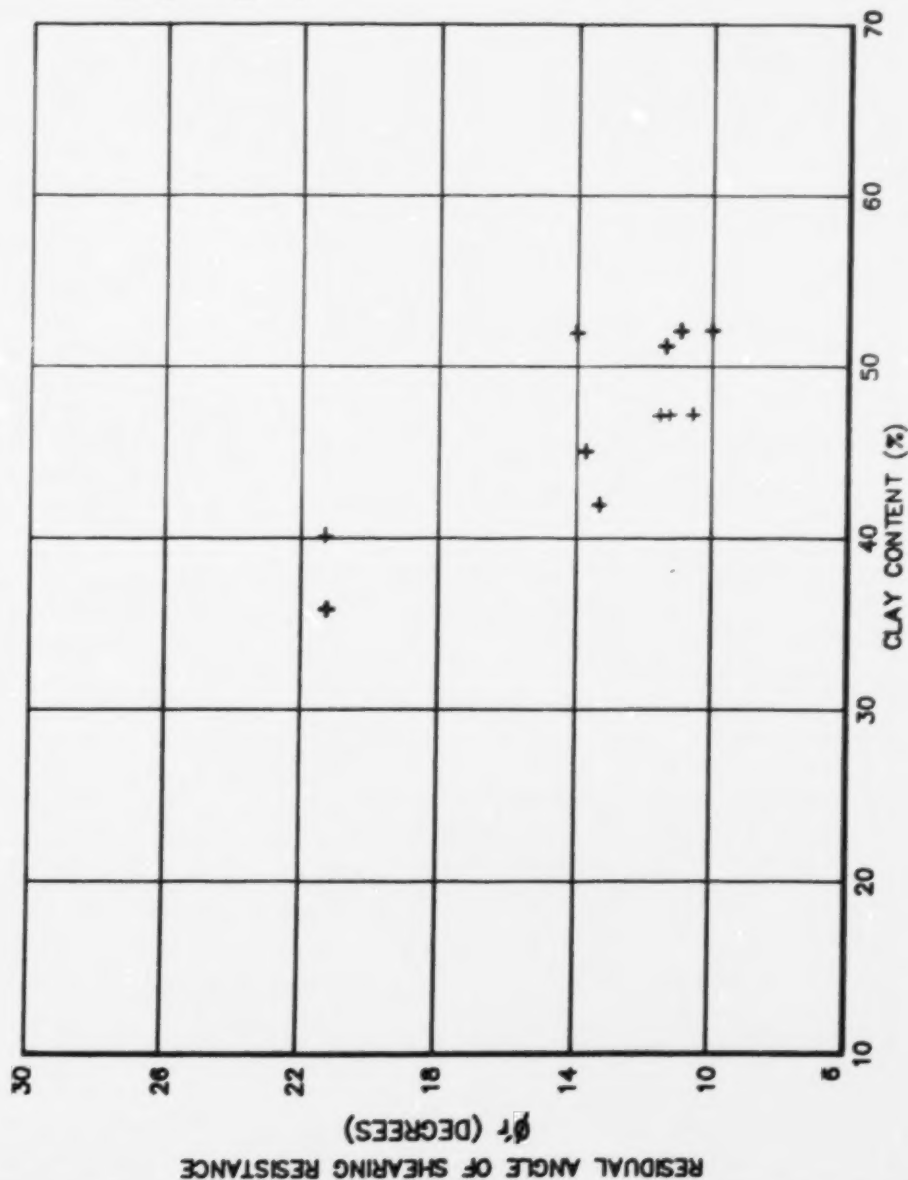


HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. 2
 CORRESPONDING TO SEAM No. R9
 REFERENCE ELEVATION AT SPILLWAY $\mathcal{L}$ = 1088.5m

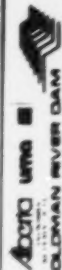


HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 UPSTREAM DIVERSION TUNNEL PORTAL
 SEAM No. 2
 CORRESPONDING TO SEAM No. R9
 REFERENCE ELEVATION AT SPILLWAY $\zeta = 1088.5\text{m}$

 ALBERTA WORKS  OLDMAN RIVER DAM
HISTOGRAM OF CLAY CONTENT AND LIQUID LIMIT SEAM 2
PLATE B-222

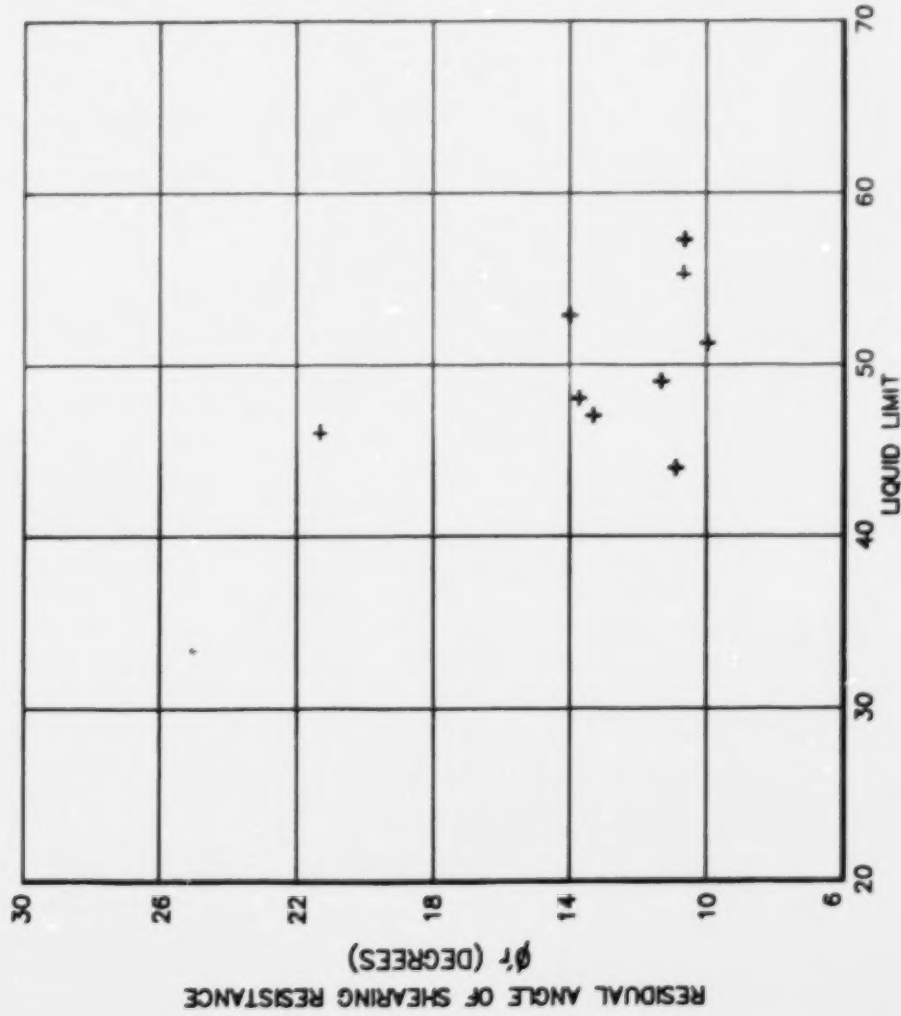


RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM No. 2
CORRESPONDING TO SEAM No. R9
REFERENCE ELEVATION AT SPILLWAY $\phi = 1088.5$ m



ϕ_r VS CLAY CONTENT
SEAM 2

PLATE B-223



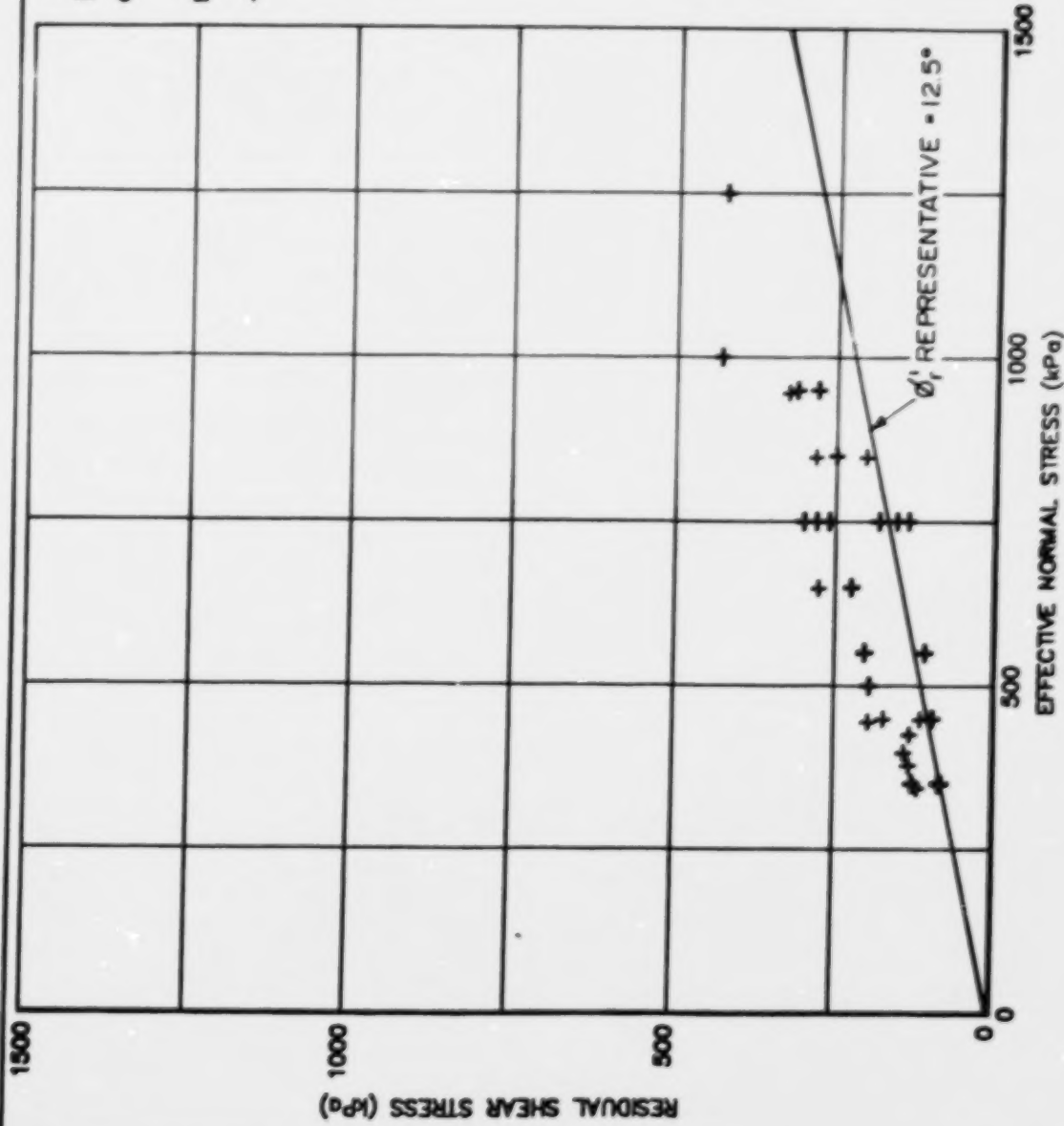
RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM No. 2

CORRESPONDING TO SEAM No. R9
REFERENCE ELEVATION AT SPILLWAY $\phi_c = 1088.5$

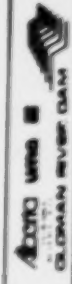


ϕ_r vs LIQUID LIMIT
SEAM 2

PLATE B-224

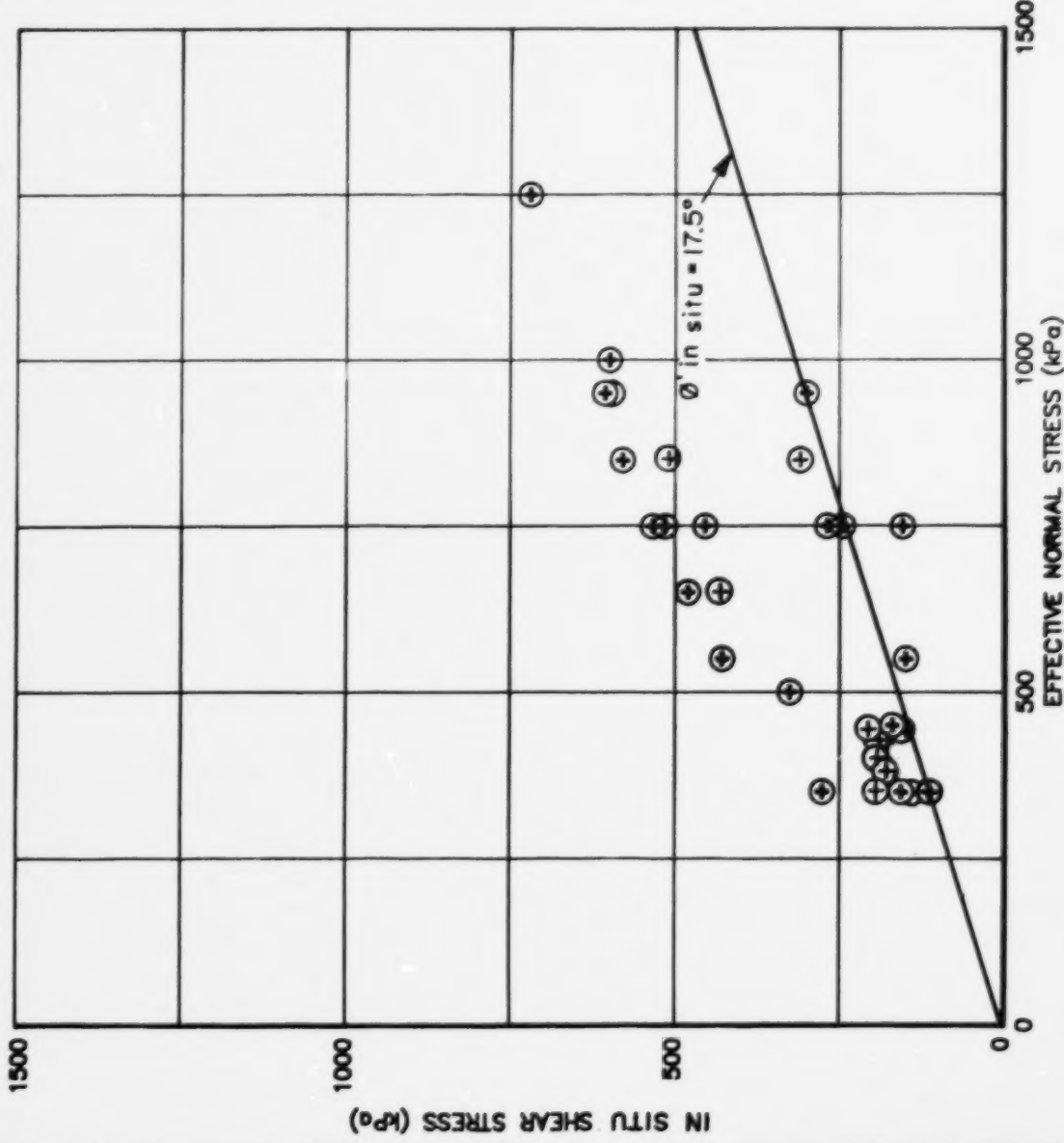


SHEAR STRENGTH - RESIDUAL
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM No. 3
CORRESPONDING TO SEAM No. 8
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



SHEAR STRENGTH - RESIDUAL
SEAM 3

PLATE B-225



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- ⊕ - 5 cm x 5 cm DIRECT SHEAR TEST SEAM SAMPLE OBTAINED FROM DRILLHOLE, 5 cm x 5 cm DIRECT SHEAR TEST
- ⊕ - SEAM SAMPLE OBTAINED FROM SHAFT OR TRENCH, 10 cm x 10 cm DIRECT SHEAR TEST.

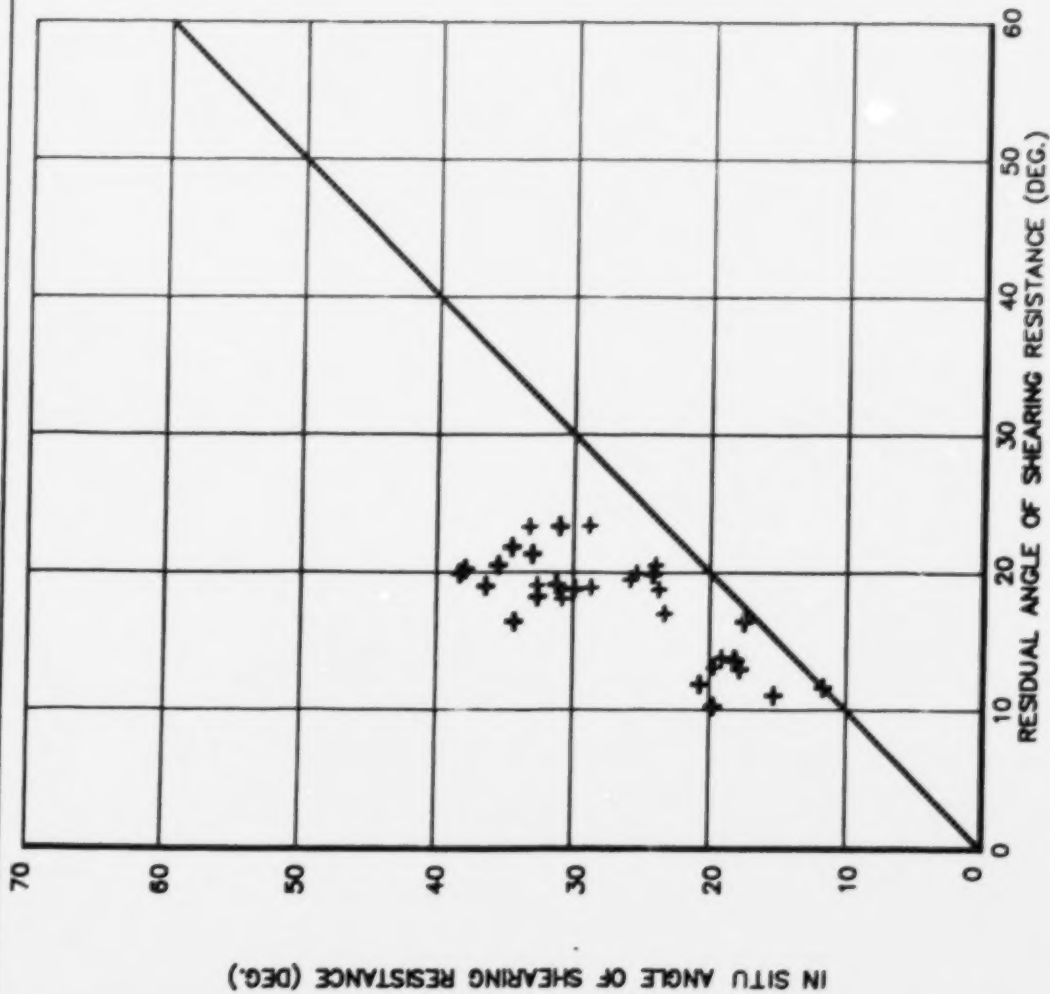


SHEAR STRENGTH - IN SITU
SEAM 3

PLATE B-226

SHEAR STRENGTH - IN SITU
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM NO. 3

CORRESPONDING TO SEAM No. R 8
REFERENCE ELEVATION AT SPILLWAY ϕ = 1087.5 m



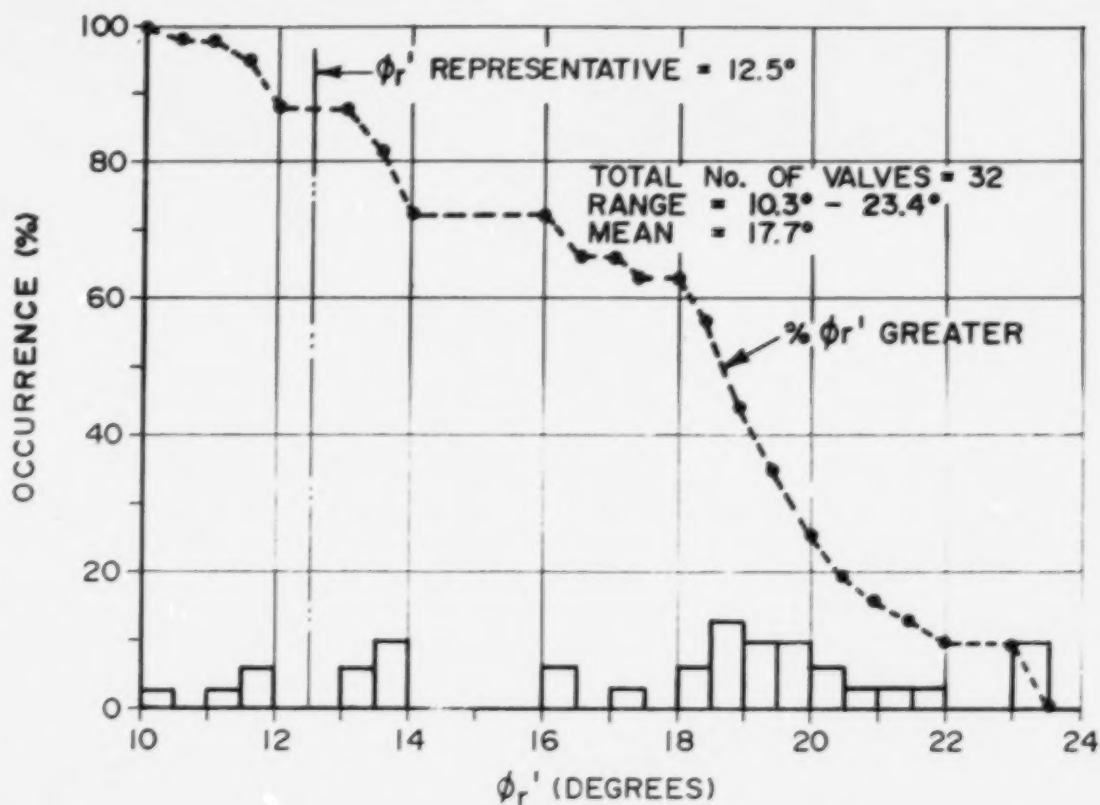
IN SITU VS RESIDUAL ANGLE OF SHEARING RESISTANCE
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM NO. 3

CORRESPONDING TO SEAM NO. R 8
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



IN SITU VS ϕ'
SEAM 3

PLATE B-227

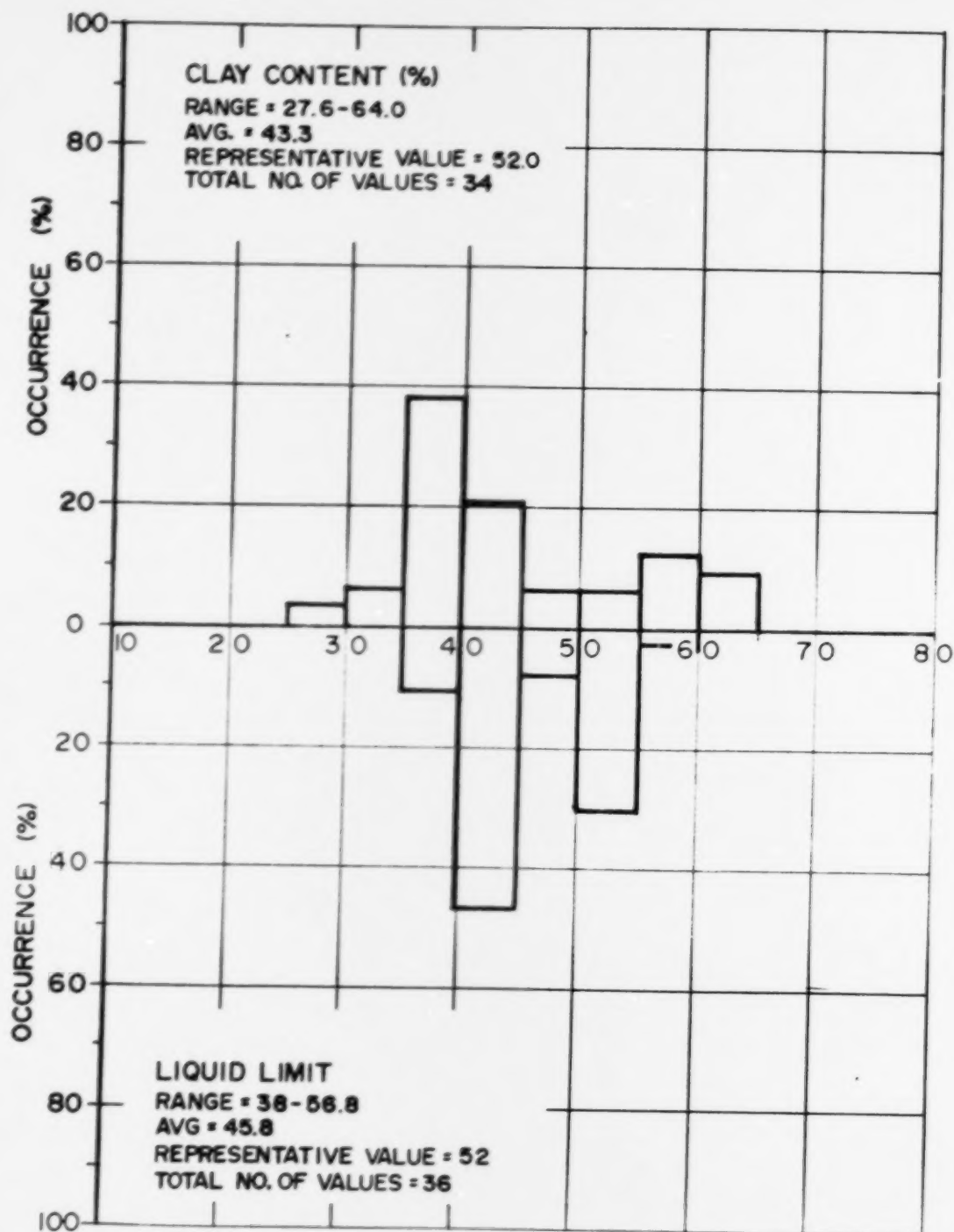


HISTOGRAM OF RESIDUAL SHEAR STRENGTH
 SEAM No. 3
 CORRESPONDING TO SEAM No. R8
 REFERENCE ELEVATION AT SPILLWAY $\mathcal{L}$ = 1087.5 m

Alberta Energy
 OLDMAN RIVER DAM

HISTOGRAM OF ϕ_r'
 SEAM 3

PLATE B-228

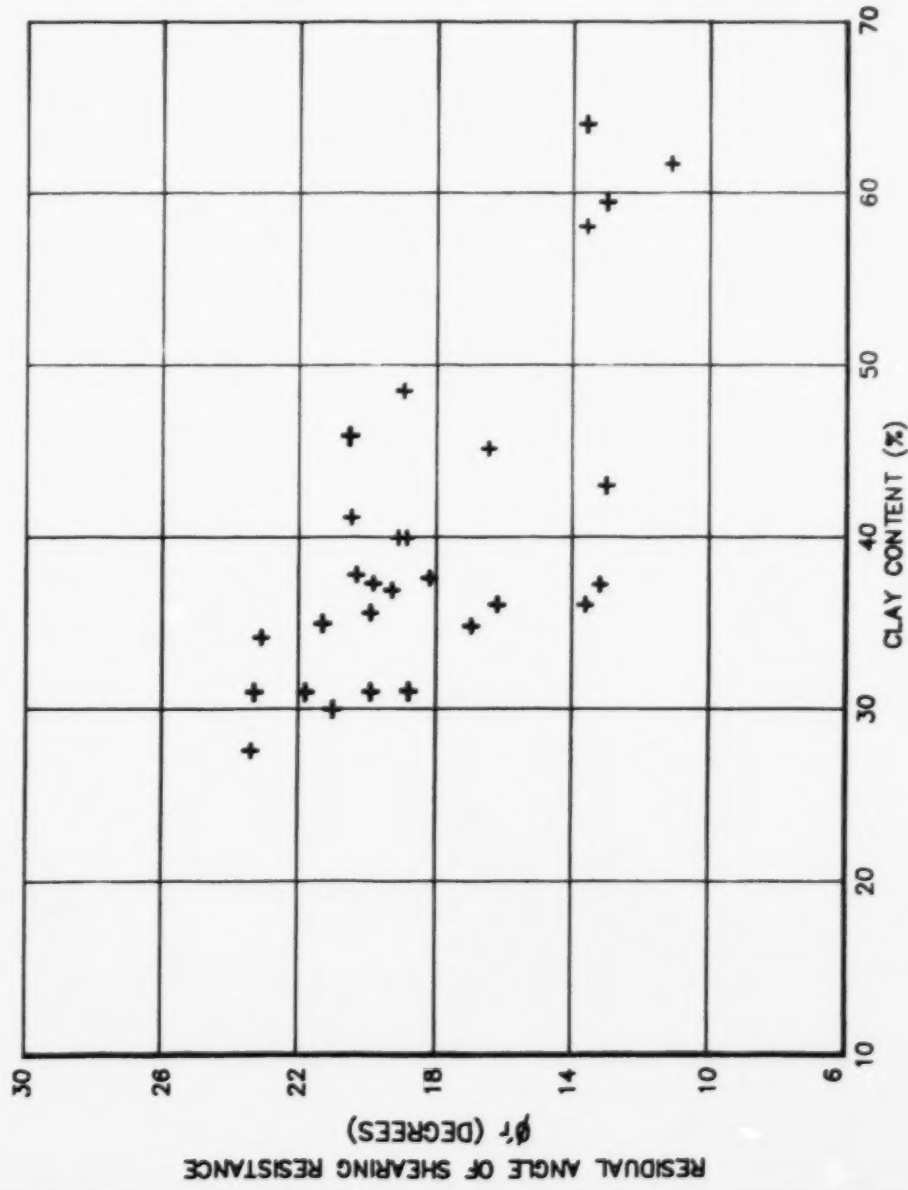


**HISTOGRAM OF CLAY CONTENT AND
 LIQUID LIMIT
 UPSTREAM DIVERSION TUNNEL PORTAL
 SEAM No. 3
 CORRESPONDING TO SEAM No. R8
 REFERENCE ELEVATION AT SPILLWAY ∇
 = 1087.5m**

Alcora  **uma** 
 OLIVARIAN RIVER DAM 

**HISTOGRAM OF CLAY CONTENT
 AND LIQUID LIMIT
 SEAM 3**

PLATE B-229



LEGEND:

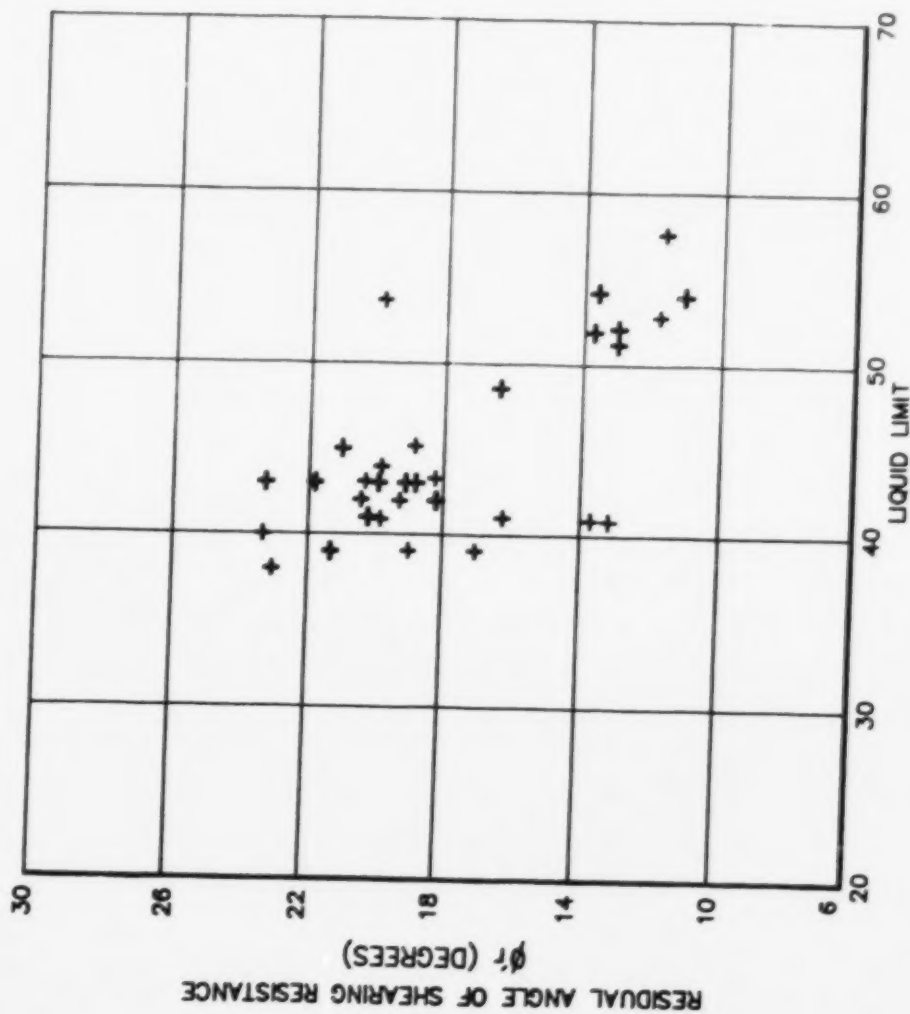
- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- +



ϕ_r VS CLAY CONTENT
SEAM 3

PLATE B-230

RESIDUAL ANGLE OF SHEARING RESISTANCE VS CLAY CONTENT
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM No. 3
CORRESPONDING TO SEAM No. R8
REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m



LEGEND:

- - INTACT CLAYSTONE SAMPLE SHEARED ALONG BEDDING
- - SEAM SAMPLE OBTAINED FROM DRILLHOLE
- +

RESIDUAL ANGLE OF SHEARING RESISTANCE VS LIQUID LIMIT
UPSTREAM DIVERSION TUNNEL PORTAL
SEAM NO. 3

CORRESPONDING SEAM NO. R8

REFERENCE ELEVATION AT SPILLWAY $\phi = 1087.5$ m

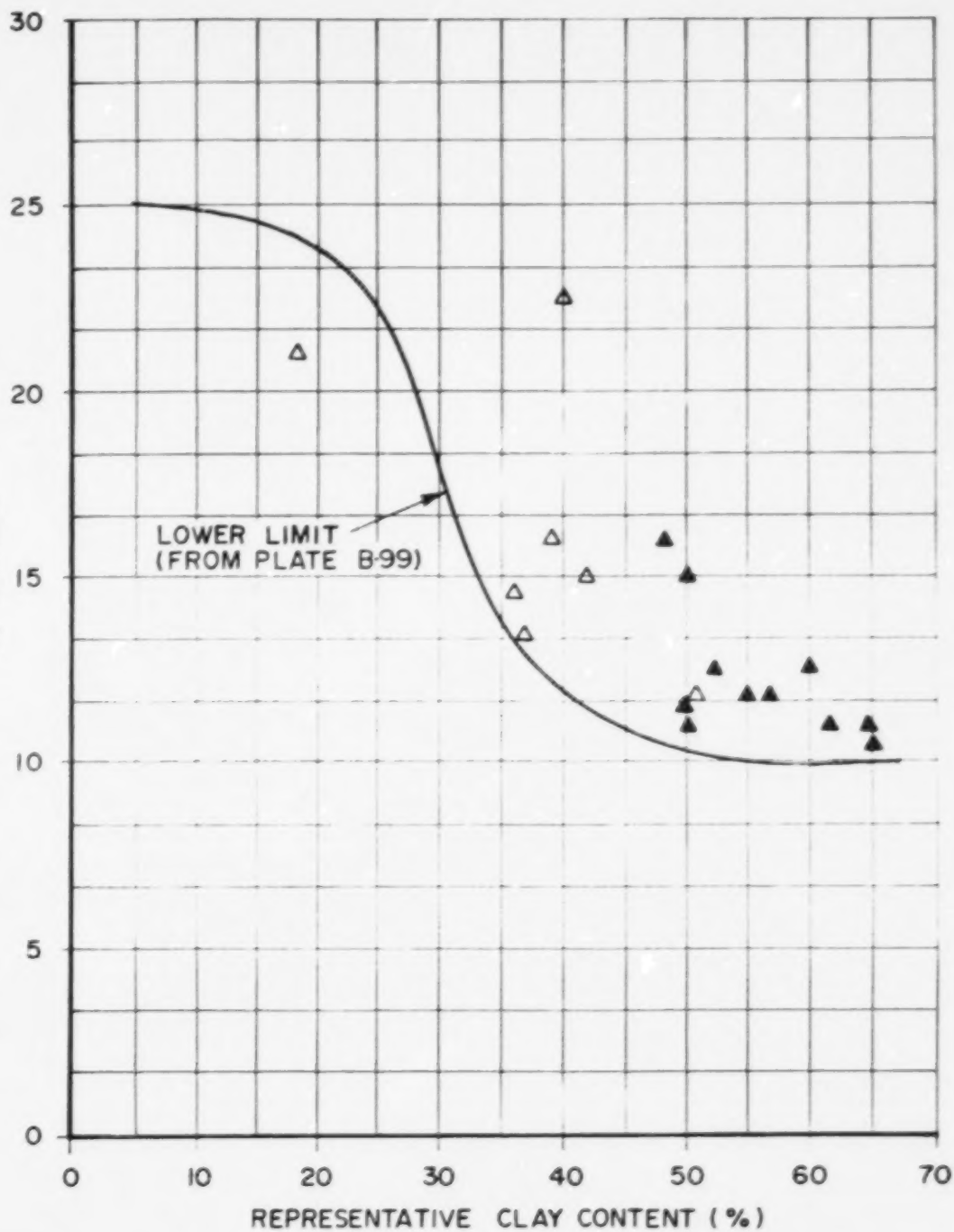


ϕ_r vs LIQUID LIMIT
SEAM 3

PLATE B-23I

REPRESENTATIVE RESIDUAL ANGLE OF SHEARING RESISTANCE

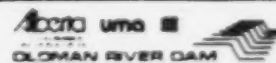
ϕ'_r DEGREES



REPRESENTATIVE ϕ'_r vs REPRESENTATIVE CLAY CONTENT FOR SEAMS

LEGEND:

- Δ - SEAMS IN RIVER VALLEY BOTTOM
- $\blacktriangle$ - SEAMS IN ABUTMENTS

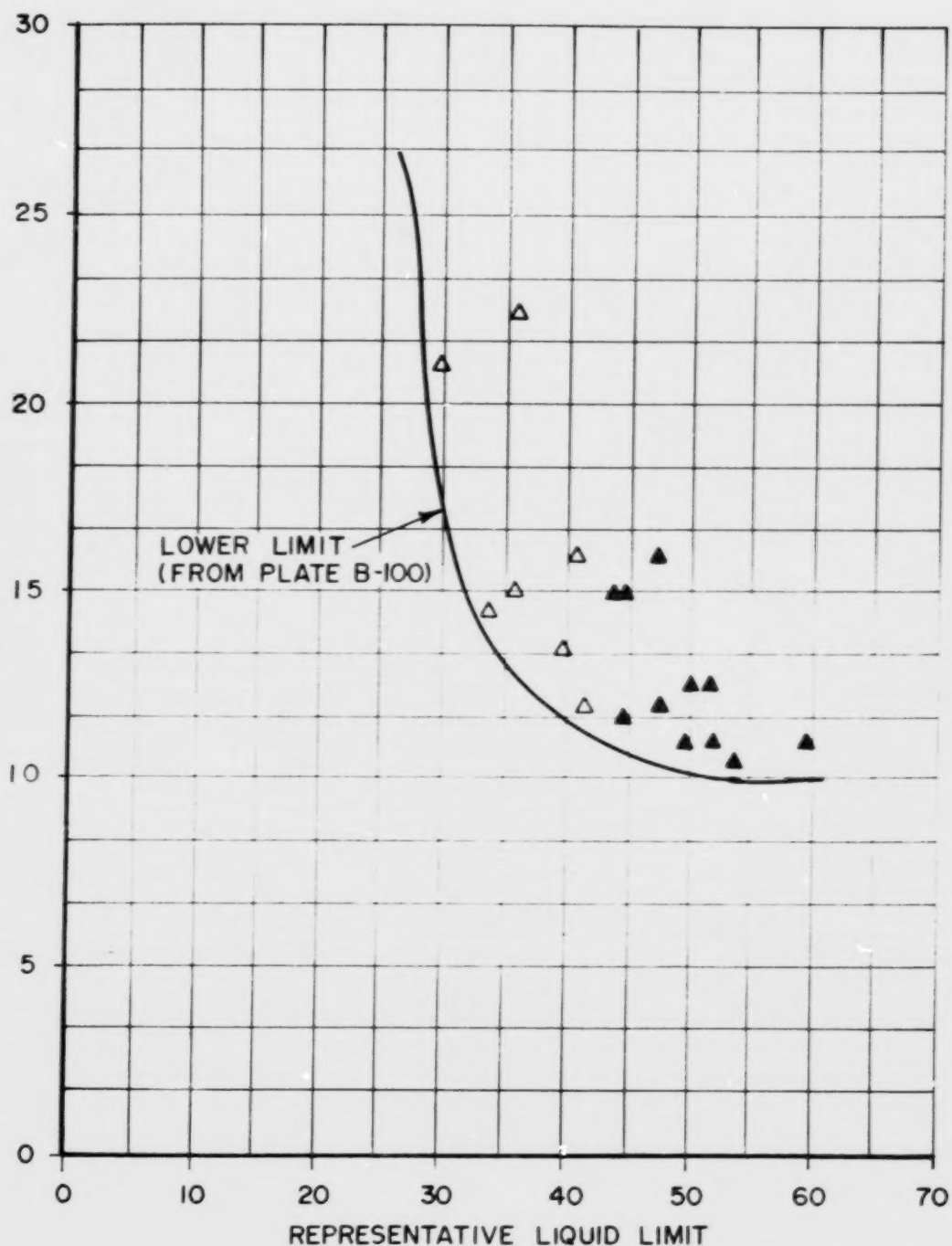


REPRESENTATIVE ϕ'_r vs CLAY CONTENT

PLATE B-232

REPRESENTATIVE RESIDUAL ANGLE OF SHEARING RESISTANCE

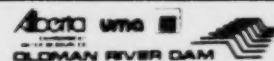
ϕ'_r DEGREES



REPRESENTATIVE ϕ'_r vs REPRESENTATIVE
LIQUID LIMIT FOR SEAMS

LEGEND:

- Δ - SEAMS IN RIVER VALLEY BOTTOM
- $\blacktriangle$ - SEAMS IN ABUTMENTS



REPRESENTATIVE ϕ'_r vs
LIQUID LIMIT

PLATE B-233

LOG FOR
EXPLORATORY SHAFT

D 95

PLATE B-234

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1.0 Structural Details

- includes description of all fabric elements that intersect the shaft with the exception of stratiform fabric.
- broken into two types of structures, each numbered from top down:
 - 1) structural feature (SF) - A single fabric element that forms a significant structural weakness in the rock mass. This is shown as a solid line.
 - 2) structural zone (SZ) - A zone containing one or more fabric elements that individually or collectively form a significant structural anomaly in the rock mass. This anomaly is outlined or illustrated by dashed lines. Representative fabric elements are occasionally shown as solid lines but are described as a 'SZ' because they form part of a larger anomaly.
- orientation of fabric elements is shown as strike, dip and dip direction. The amount of steel used in the cage and shaft support precluded use of a compass, so orientations and dip directions are given as directions only.
- structural zones which represent removal of part of the wall of the shaft fall into three categories:
 - 1) rockfall zones - A mass of rock bounded by fabric elements.
 - 2) overbreak zones - A mass of rock bounded by irregular surfaces considered to be random planes of breakage.
 - 3) cavities - strata containing closely spaced fissures which have been washed out during shaft sinking.
- short forms used include:

r = surface roughness measured in millimetres

pp = pocket penetrometer reading (compressive strength) measured in tons/ft²

kp = knife penetration measured in millimetres.

2.0 Lithological Details

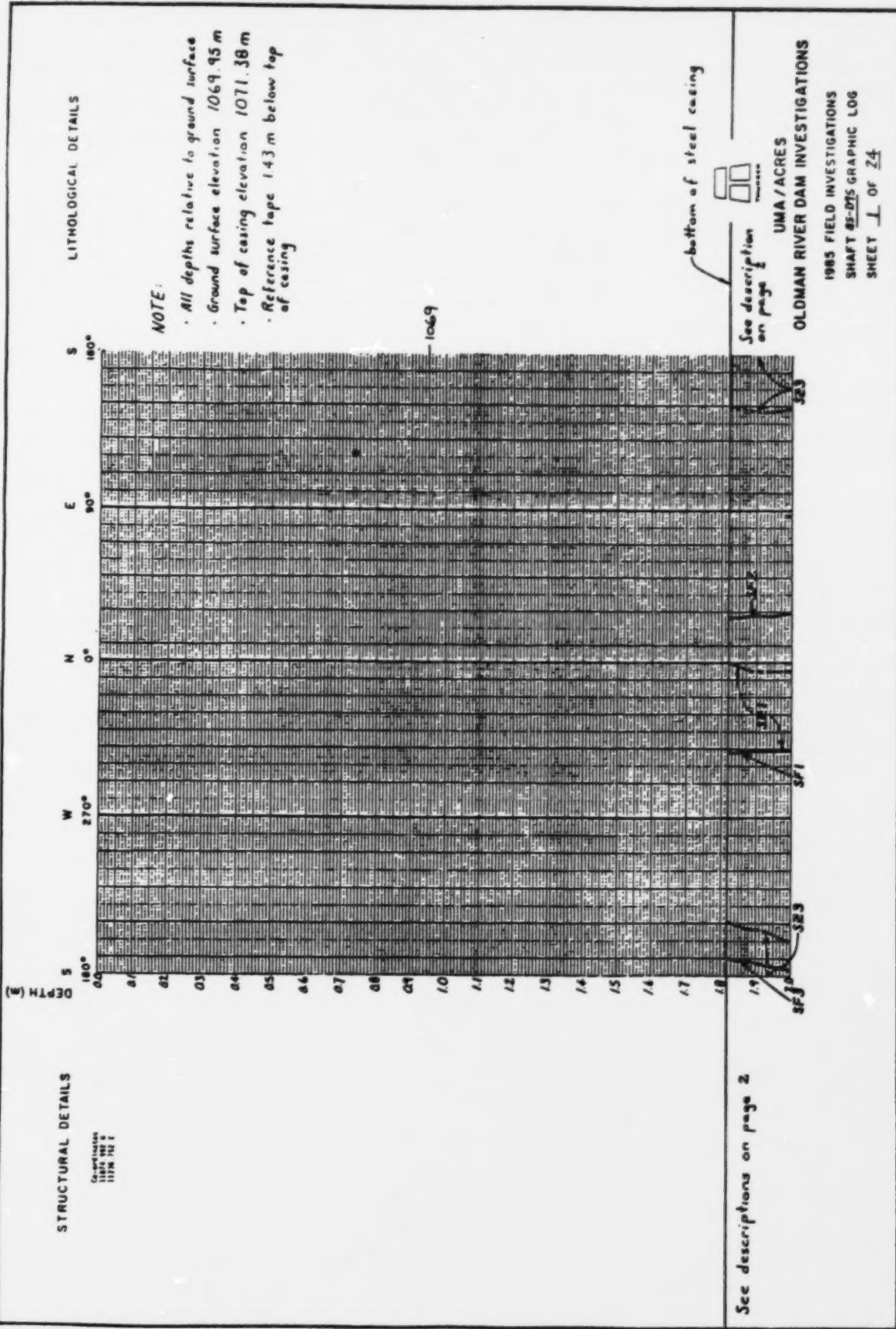
- the rock section encountered by the shaft is broken into units and sub units.
- units are shown in block letters separated by thick lines.
- sub units are shown in lower case letters and are separated by thin lines.

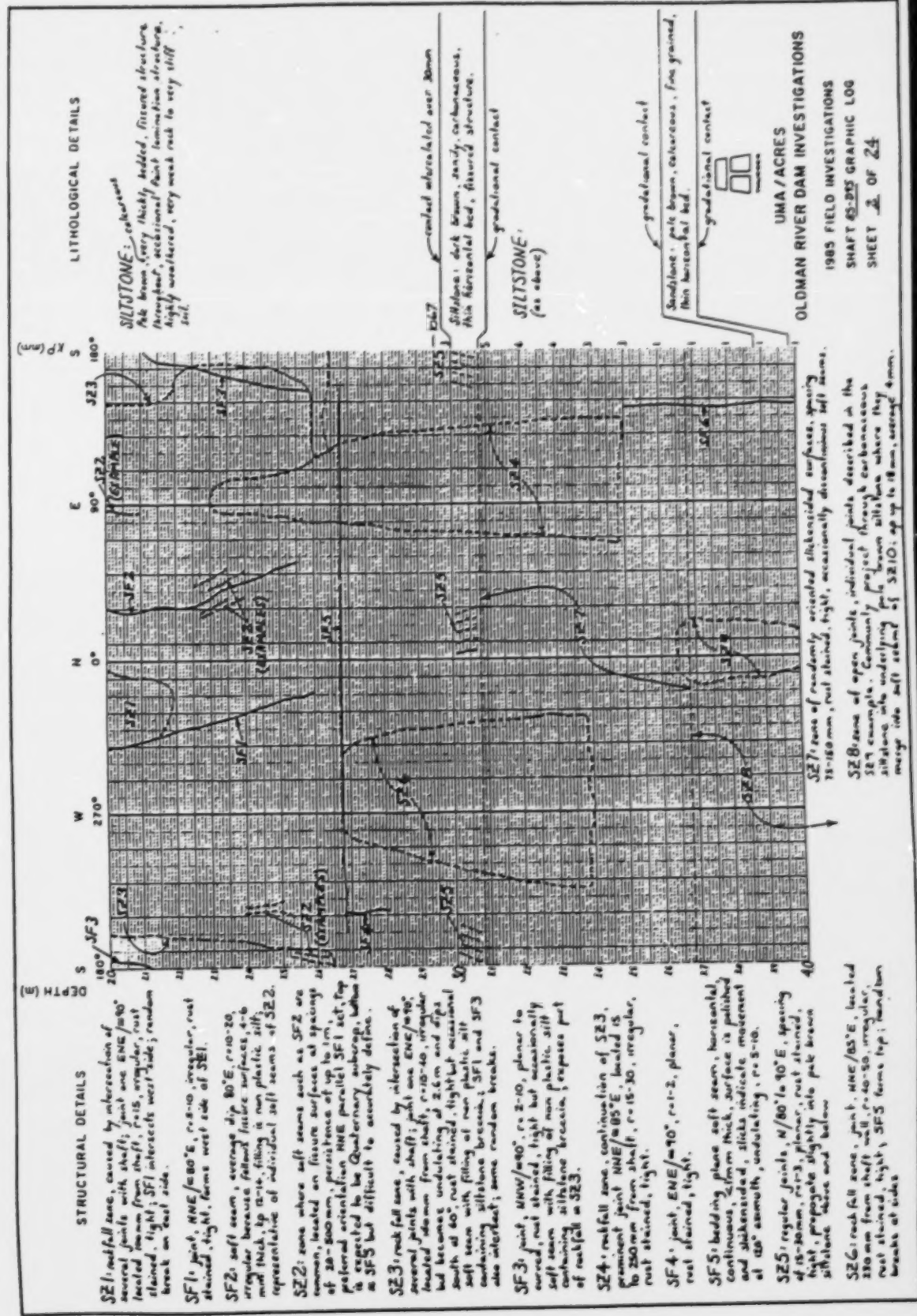
THURBER CONSULTANTS LTD.

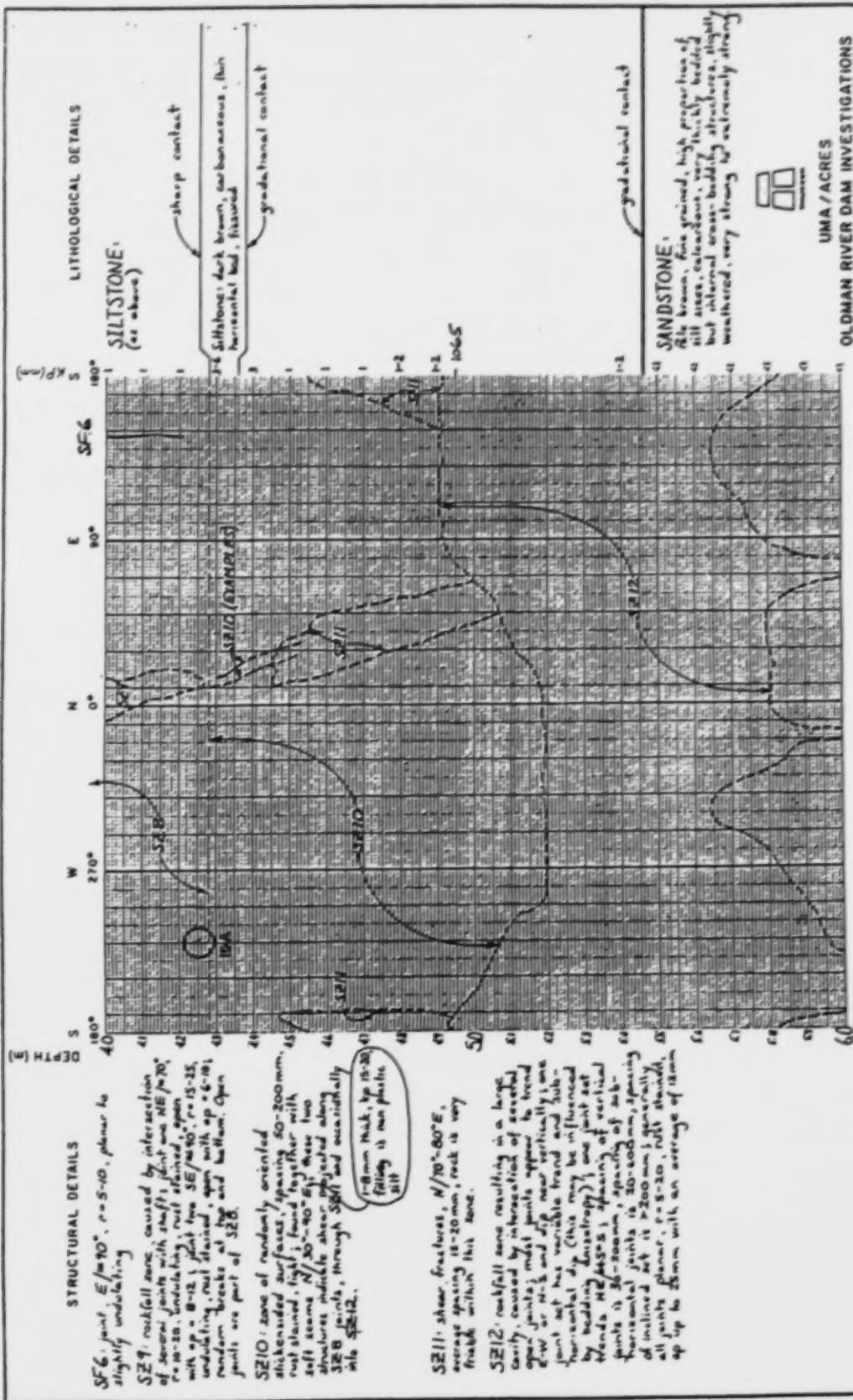
- zones containing stratiform features of interest are outlined by thin lines which extend half way across the 'Lithological Details' column.
- stratiform fabric is described under 'Lithological Details' while other fabric elements are described under 'Structural Details'.
- the structure of sandstones and occasionally siltstones is visible because of sorting of dark minerals (argillite, volcanics, coal, claystone or siltstone fragments) into beds or laminae. These are described only as bedding or lamination structures because subtle differences in mineralology could not be discerned in the limited light available in the shaft.

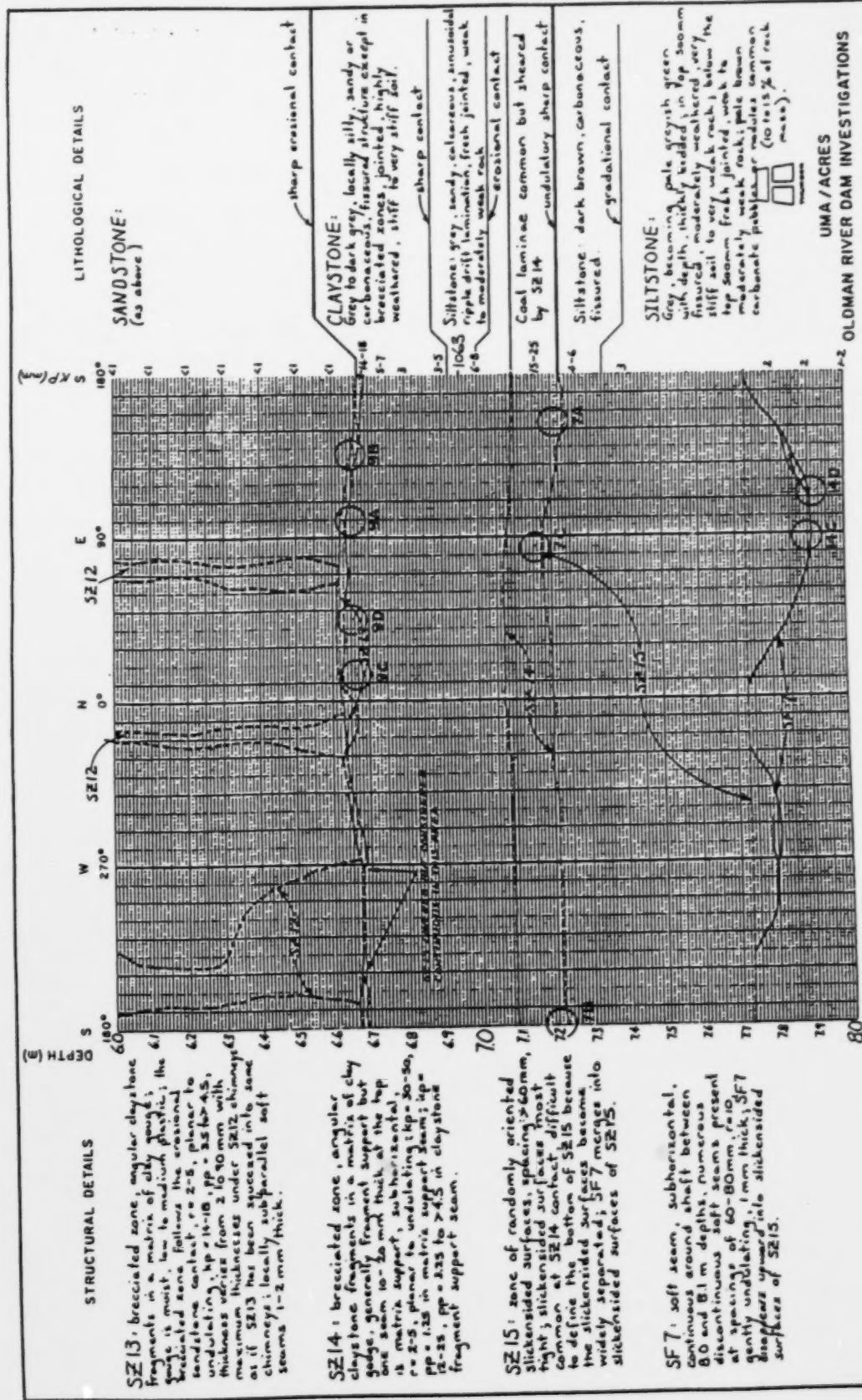
3.0 General Comment

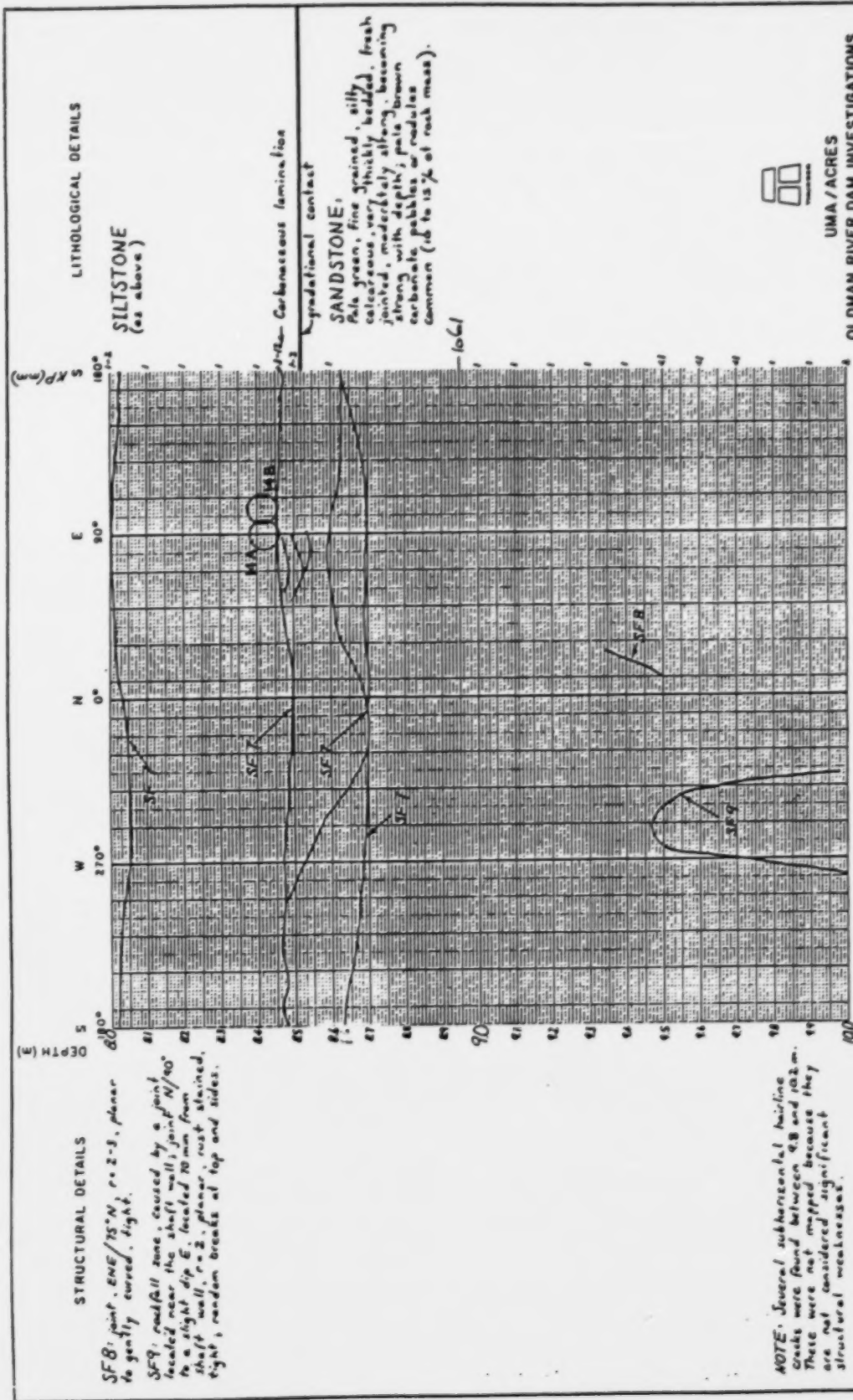
- clarification of aspects not covered in the above sections can be made before the final report is prepared. Please direct any queries or suggestions to myself so this legend can be upgraded accordingly.





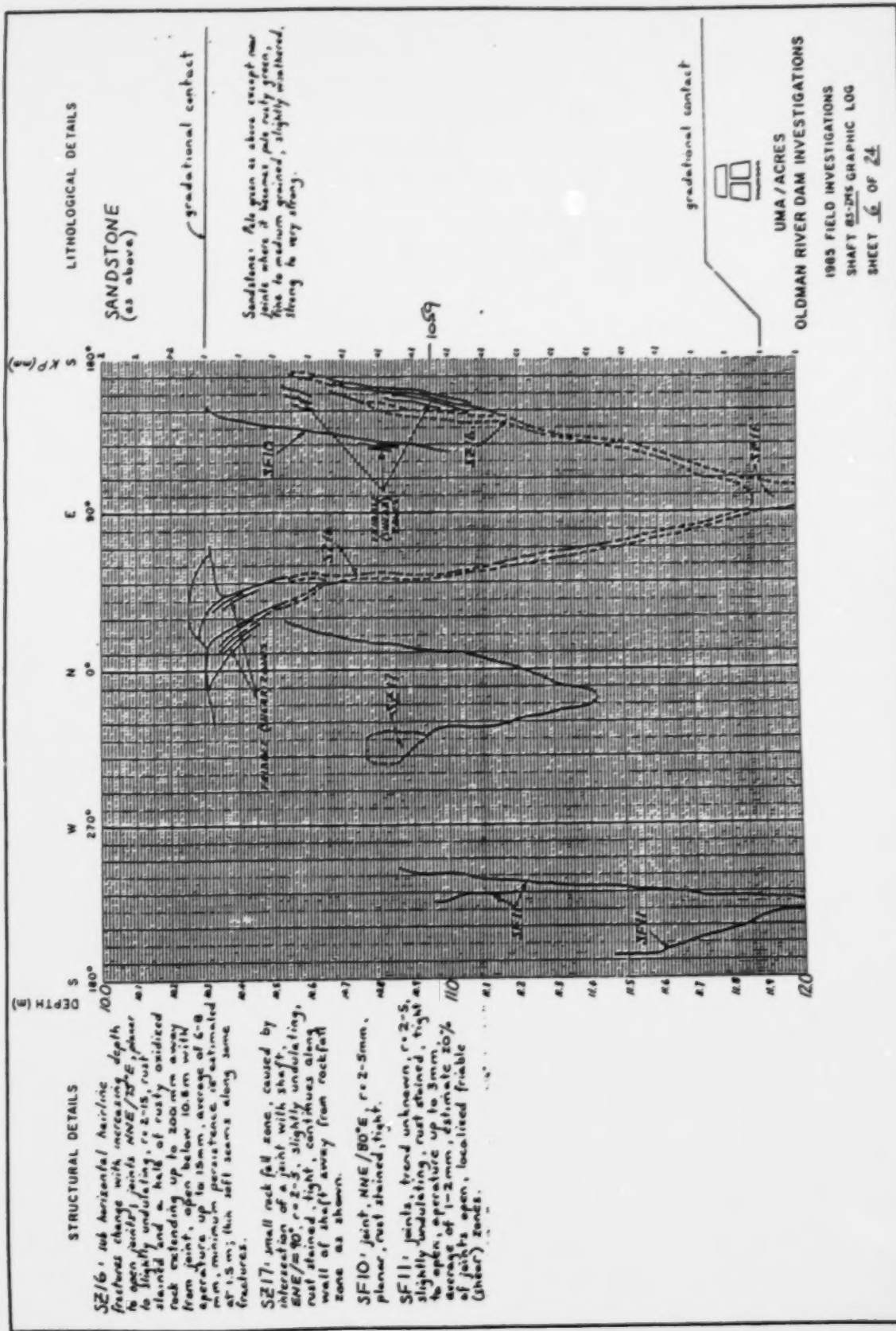


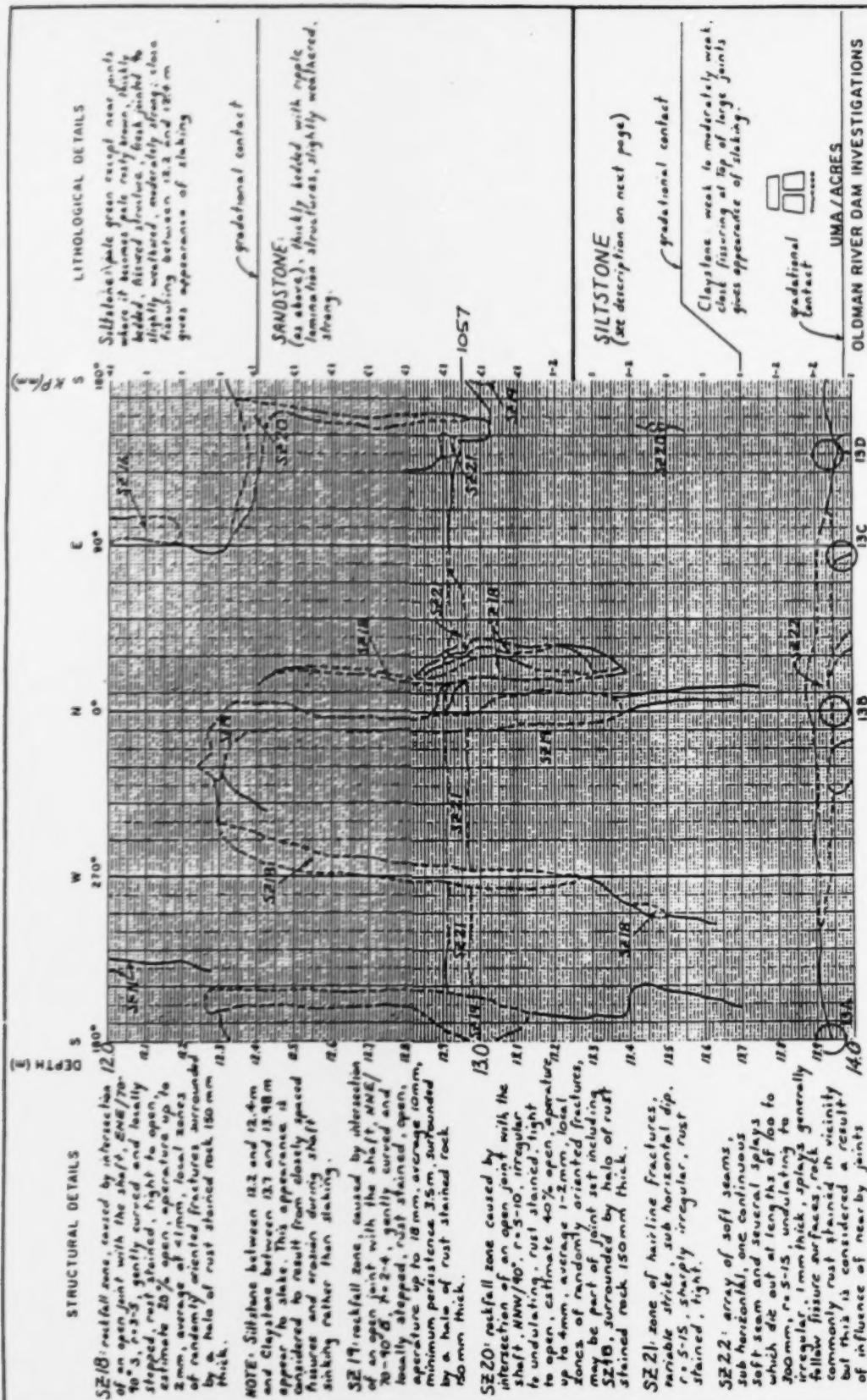


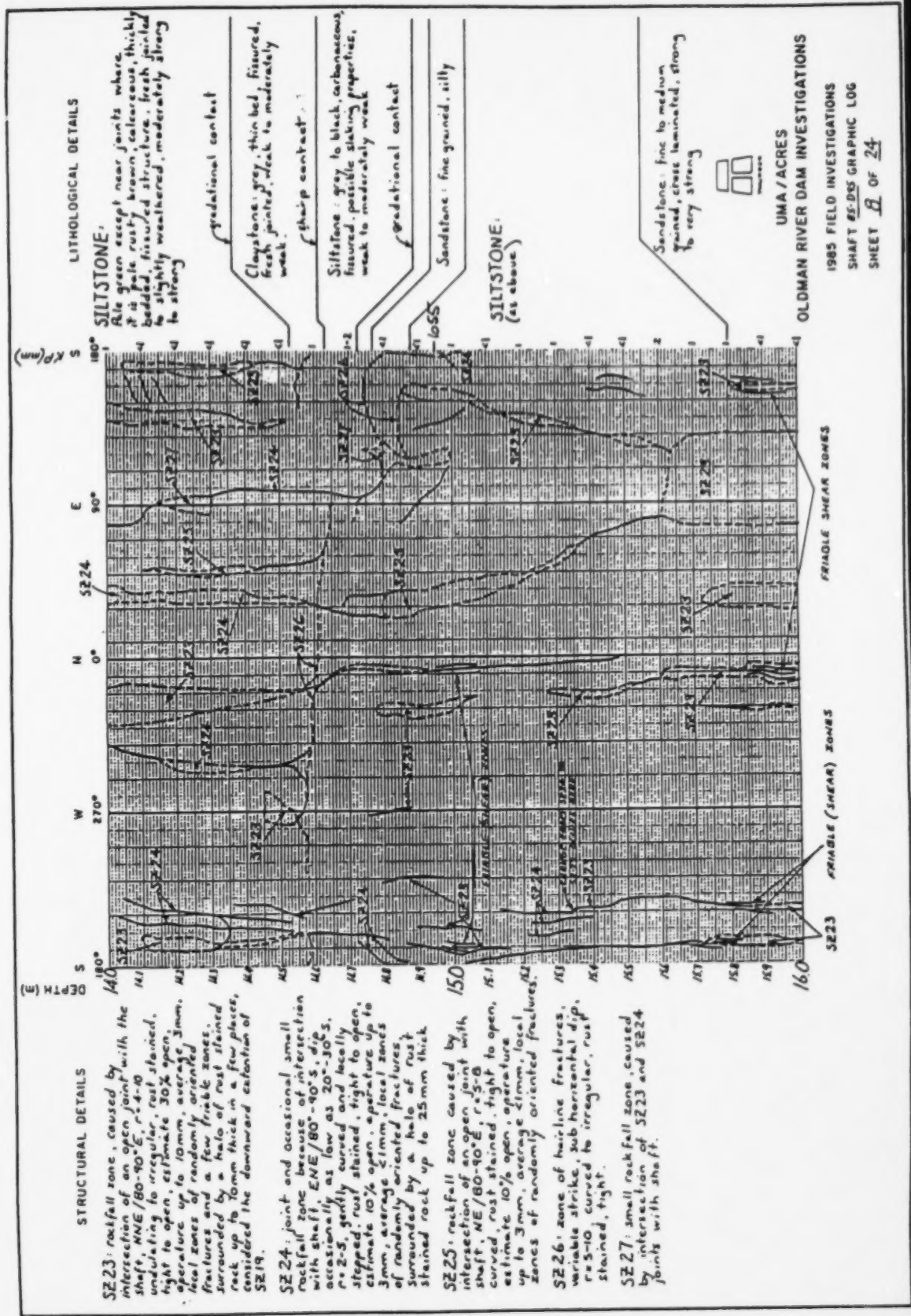


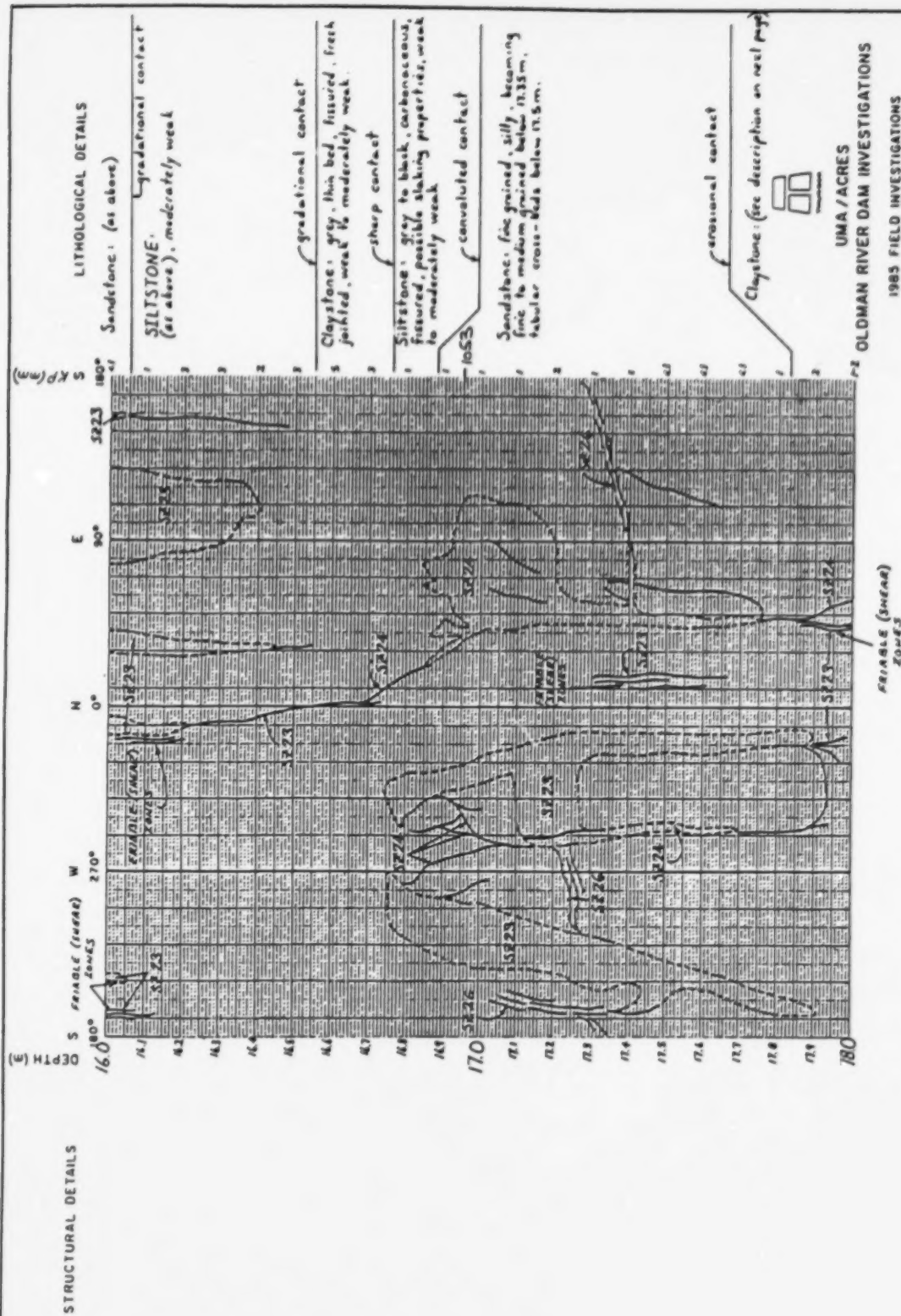
UMA / ACRES
OLDMAN RIVER DAM INVESTIGATIONS

1985 FIELD INVESTIGATIONS
SHAFT 85-05 GRAPHIC LOG
SHEET 5 OF 24









STRUCTURAL DETAILS

SZ 28: Brecciated zone, angular claystone fragments in matrix of clay gouge. Transition from fragment support to matrix support, sub horizontal (follows) within 20 to 30 mm of lower contact with sandstone, PZ-S, planar to undulating, thickness range from 10-18 mm; hp 25-40, pp 20-30, 2.5 in matrix support sections; hp 20-30, pp 2-4.5 in fragment support sections.

SZ 29: Zone of discontinuous soft seams and brecciated zones, range from 21 mm to 18 mm thick, continuous up to 380 mm; as described in SZ 28.

SZ 30: Zone of discontinuous hairline cracks, random strike, sub horizontal, c. 5-15, irregular.

SF 12: Cavities, considered the result of spalling caused by stress release.

DEPTH (m)

180°

270°

0°

90°

180°

S.P. (m)

LITHOLOGICAL DETAILS

Claystone: gray to dark gray, fissured structure throughout except in brecciated zones, moderately weathered, very weak rock, erosion of up to 80-100 mm of material on the radius around the circumference of the shaft gives the appearance of slabbing.

Sandstone: pale green to gray, fine grained, silty, thickly bedded, locally concretionary, structures and graded, carbonaceous laminae, fresh jointed strongly, pale brown carbonate pebbles or nodules up to 18 mm in diameter below 18.8 m, make up less than 10% of the rock mass.

gradational contact

SILTSTONE (as above)

gradational contact

Sandstone: (as above 18.31-18.15 m)



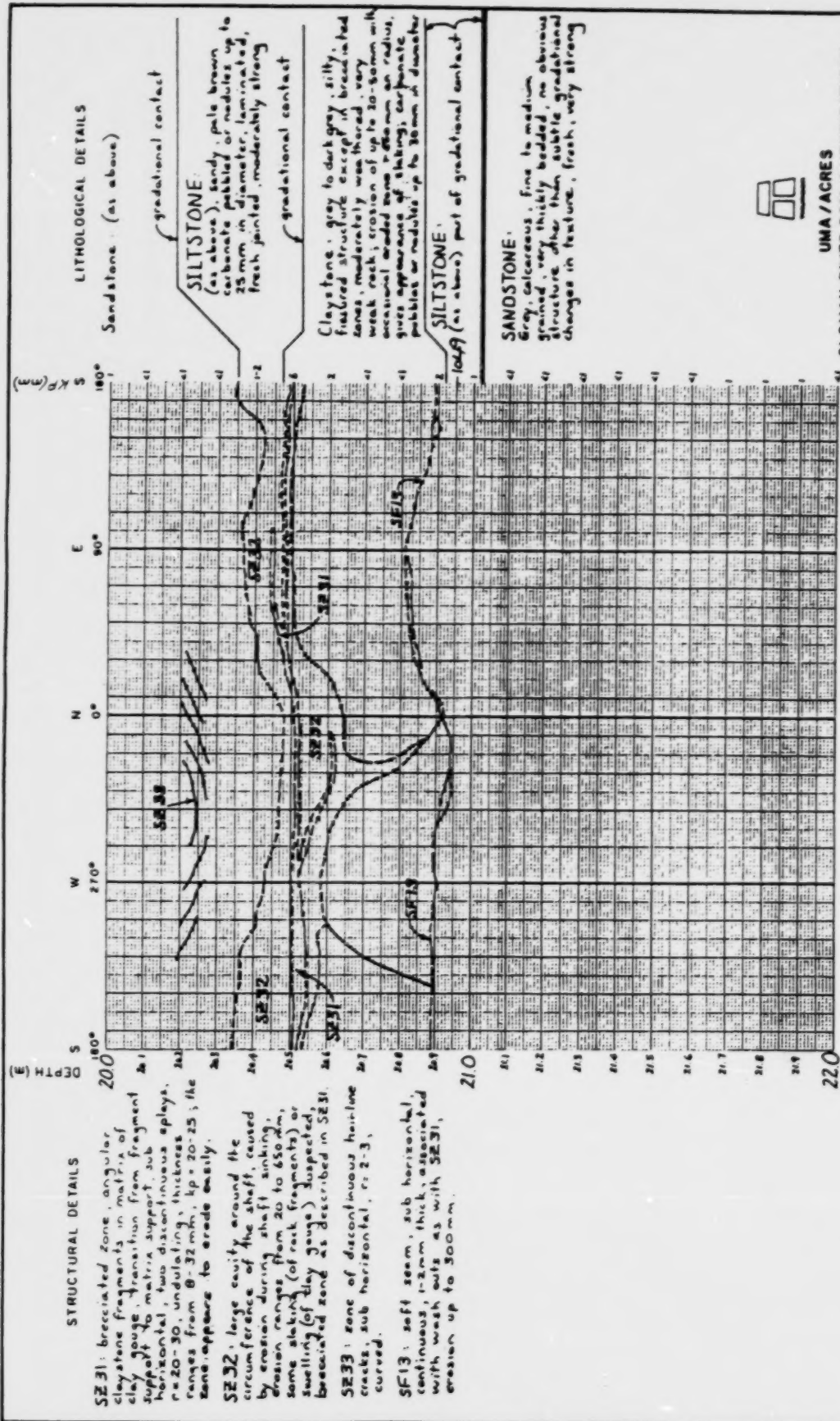
UMA / ACRES

OLDMAN RIVER DAM INVESTIGATIONS

1985 FIELD INVESTIGATIONS

SHAFT #5-P55GRAPHIC LOG

SHEET 12 OF 24



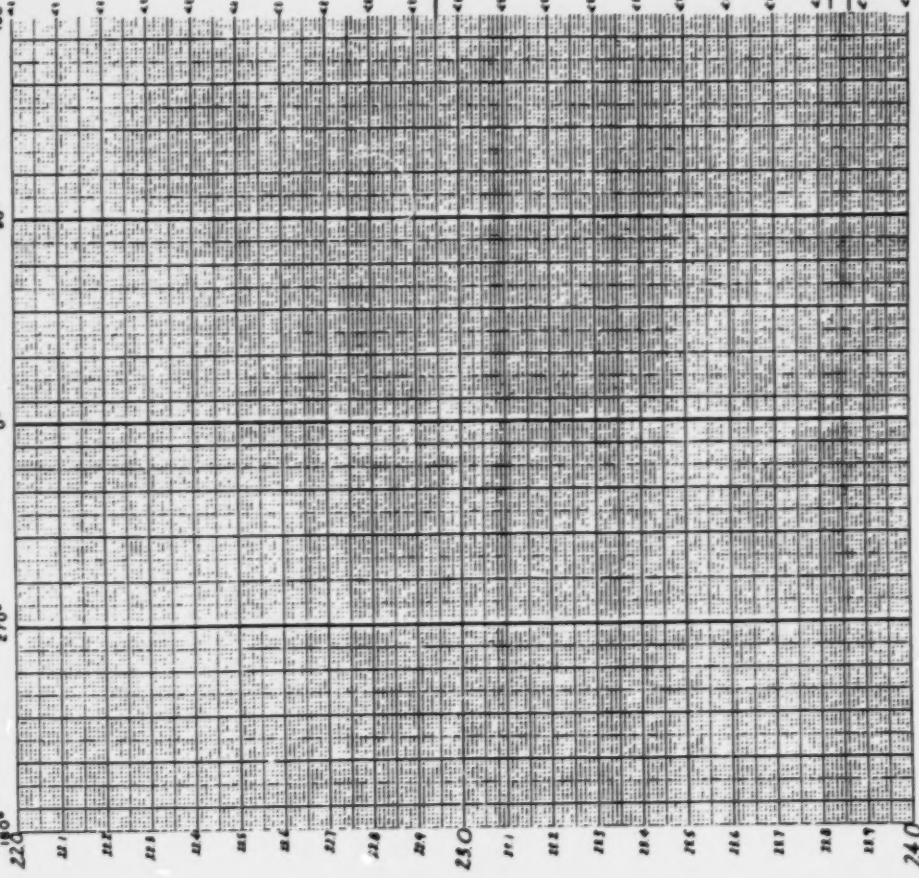
STRUCTURAL DETAILS

DEPTH (m)

S KP (m)

LITHOLOGICAL DETAILS

SANDSTONE
(as above)



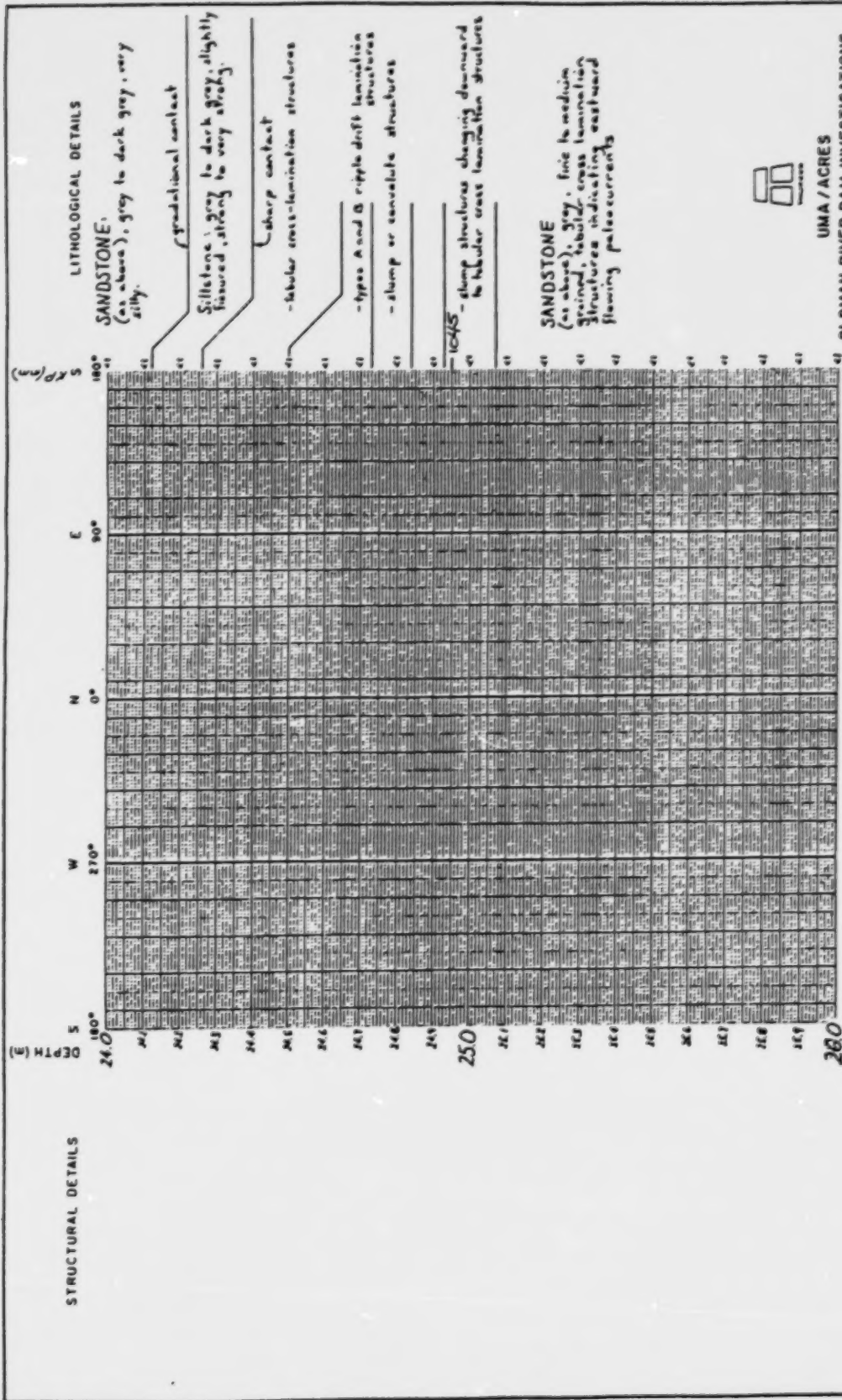
1047

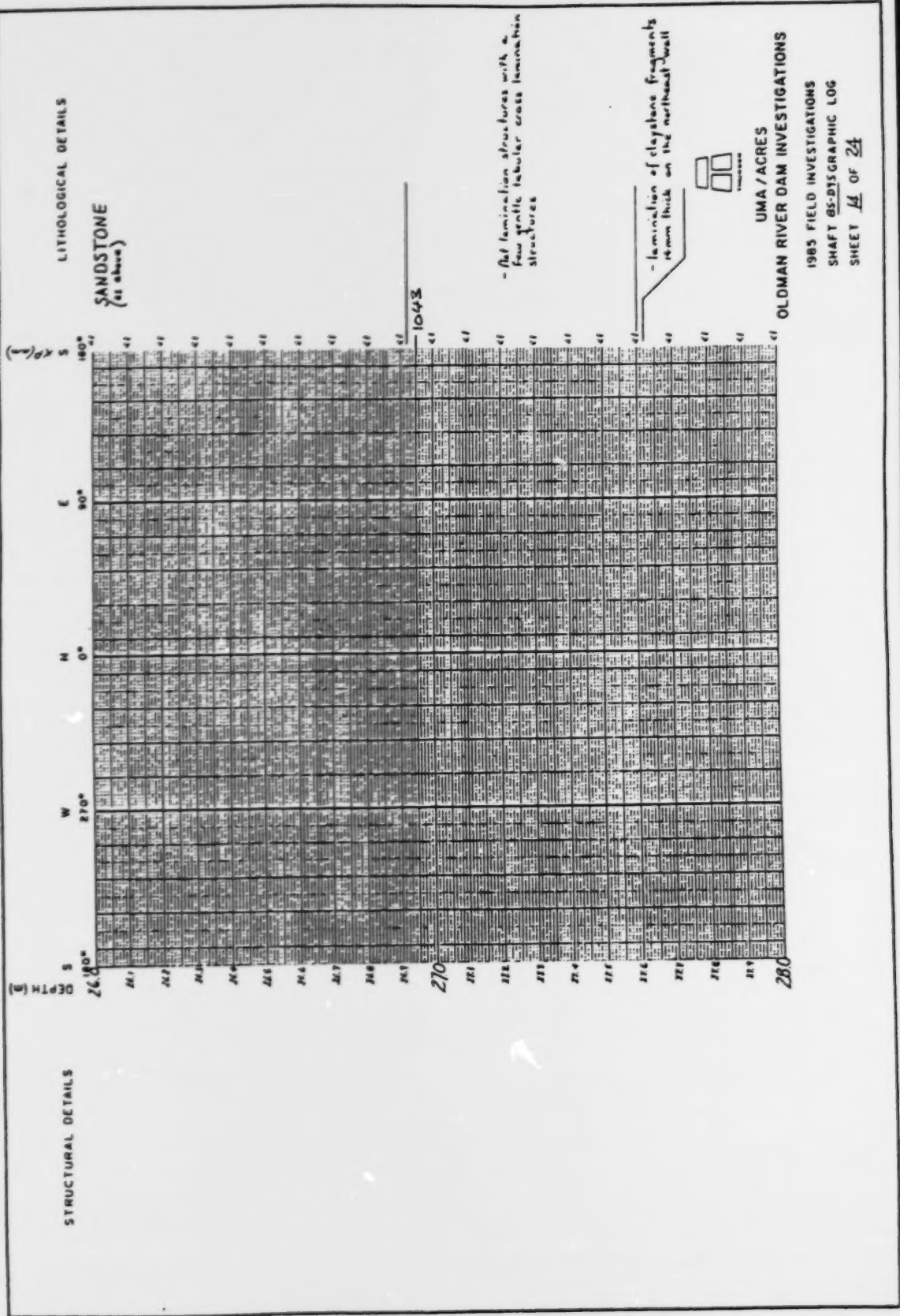
gradational contact
Siltstone: gray to dark gray,
slightly fissured, strong to
very strong
sharp contact



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OLDMAN RIVER DAM INVESTIGATIONS

1985 FIELD INVESTIGATIONS
SHAFT 65-D15 GRAPHIC LOG
SHEET 12 OF 24





STRUCTURAL DETAILS

SF14. joint, E/45°S, c. 1-2, 1941

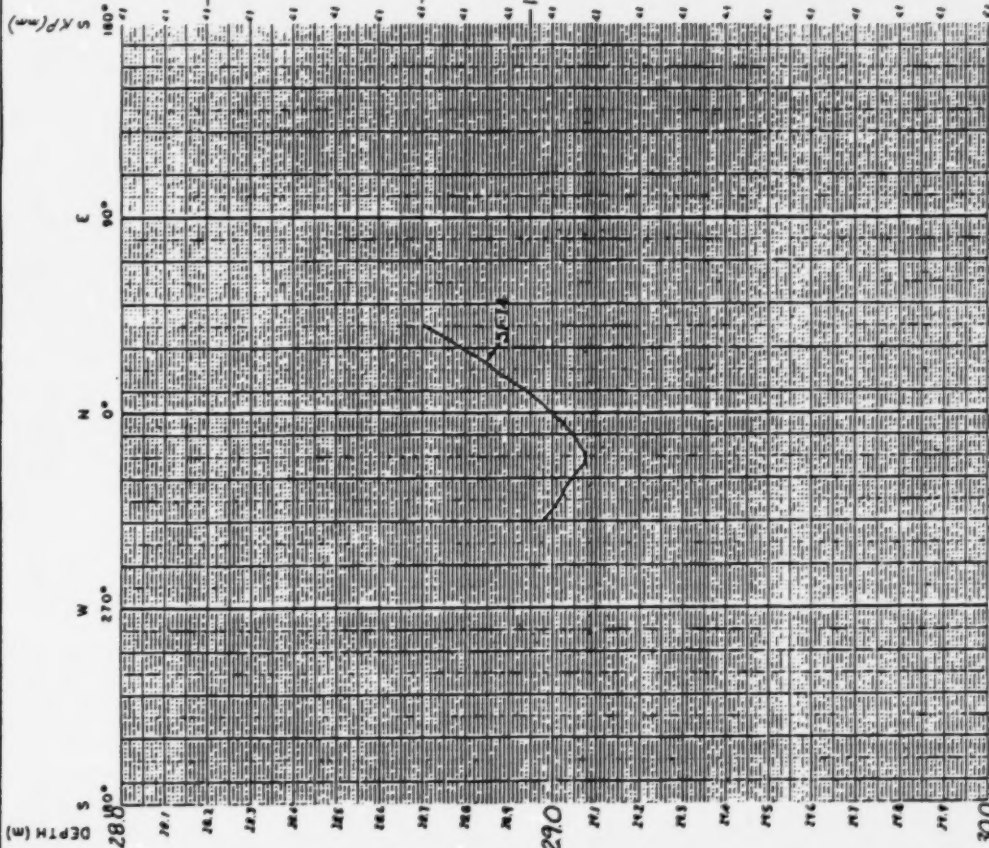
DEPTH (m)

LITHOLOGICAL DETAILS

SANDSTONE
(as above)

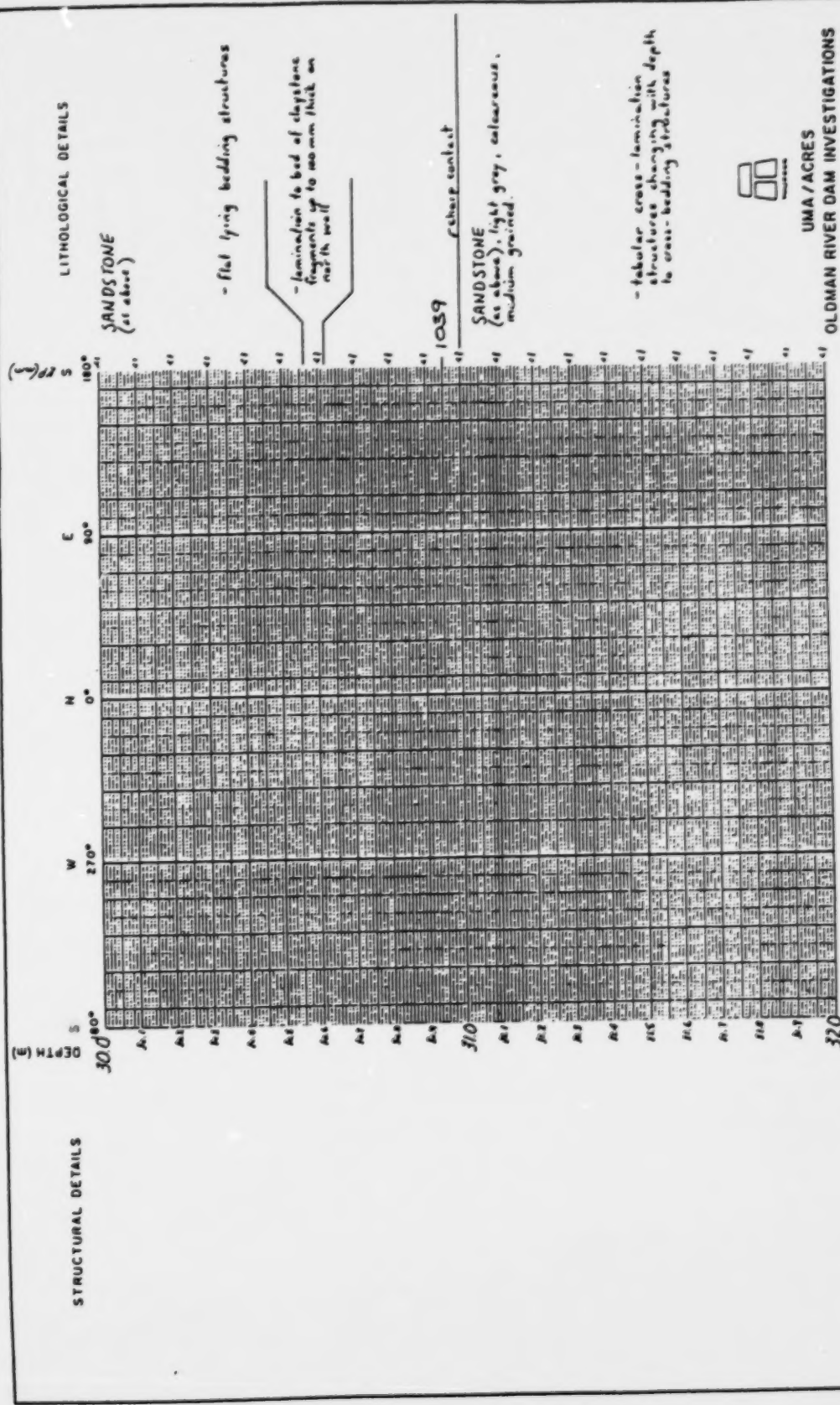
- tabular cross-bedding structures

- flat lying bedding structures

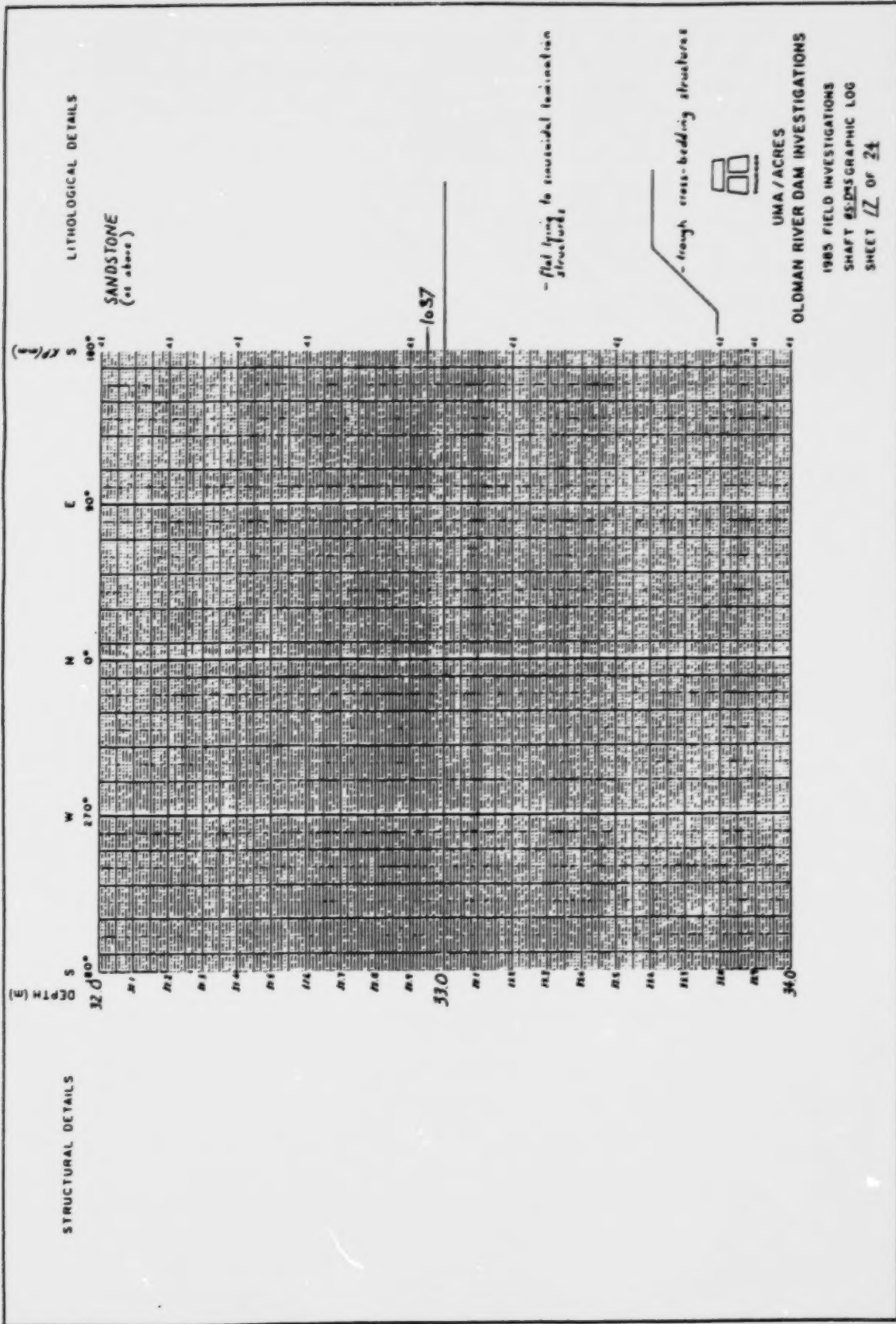


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1985 FIELD INVESTIGATIONS
SHAFT BS-DMS GRAPHIC LOG
SHEET 15 OF 24



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 OLDMAN RIVER DAM INVESTIGATIONS
 1985 FIELD INVESTIGATIONS
 SHEET #5-BYS GRAPHIC LOG
 SHEET 16 OF 24



STRUCTURAL DETAILS

SF15, over break zone, associated with weaknesses near the contact of homogeneous sandstone beds and beds rich in claystone fragments; possible spalling related to stress release.

DEPTH (m)
34.0

S KP (mm)
180°

LITHOLOGICAL DETAILS

SANDSTONE
(41 above)

- tabular cross-bedding structures

erosional contact

SANDSTONE:
(as above), medium to coarse grained,
60% claystone fragments on east wall
erosional contact

SANDSTONE:
(as above), medium to coarse grained,
tabular cross bedding structures
erosional contact

1035

SANDSTONE & CLAYSTONE FRAGMENTS
Claystone fragments, subangular to
subrounded, up to 10mm diameter in a
matrix of coarse grained sandstone;
matrix support, tabular cross-bedding
structure; fresh, strong

erosional contact

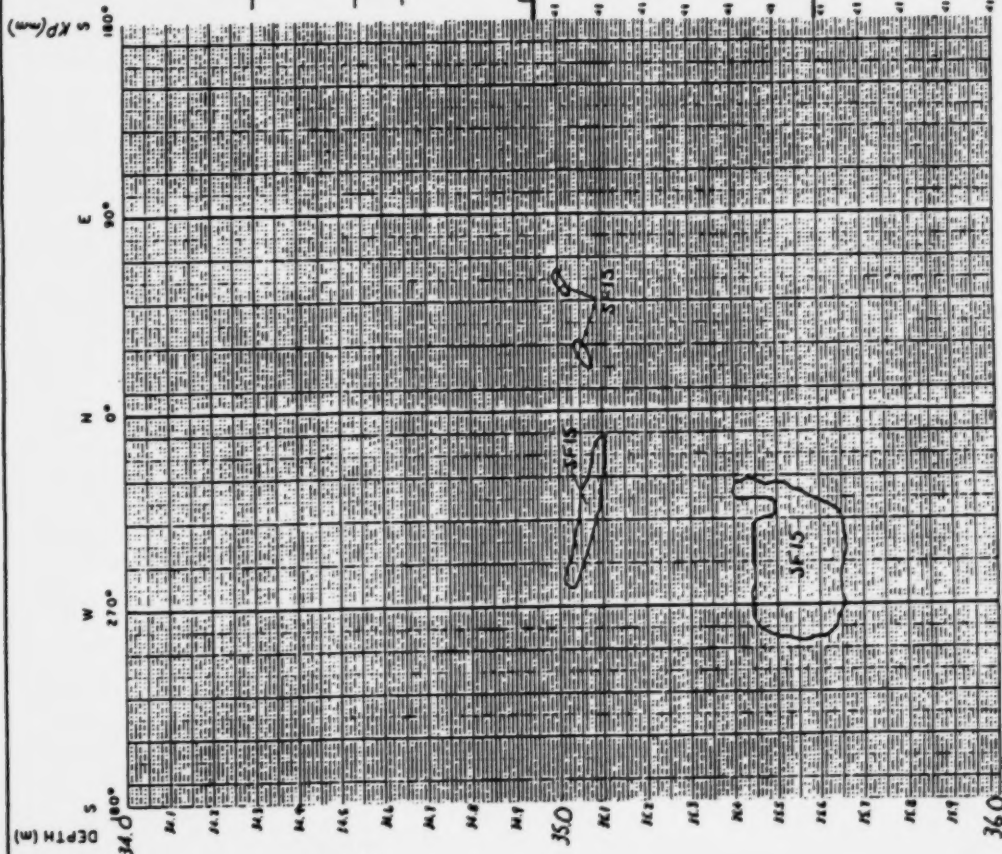
SANDSTONE
Grey, coarse grained, tabular cross-
bedding structure, fresh, very strong

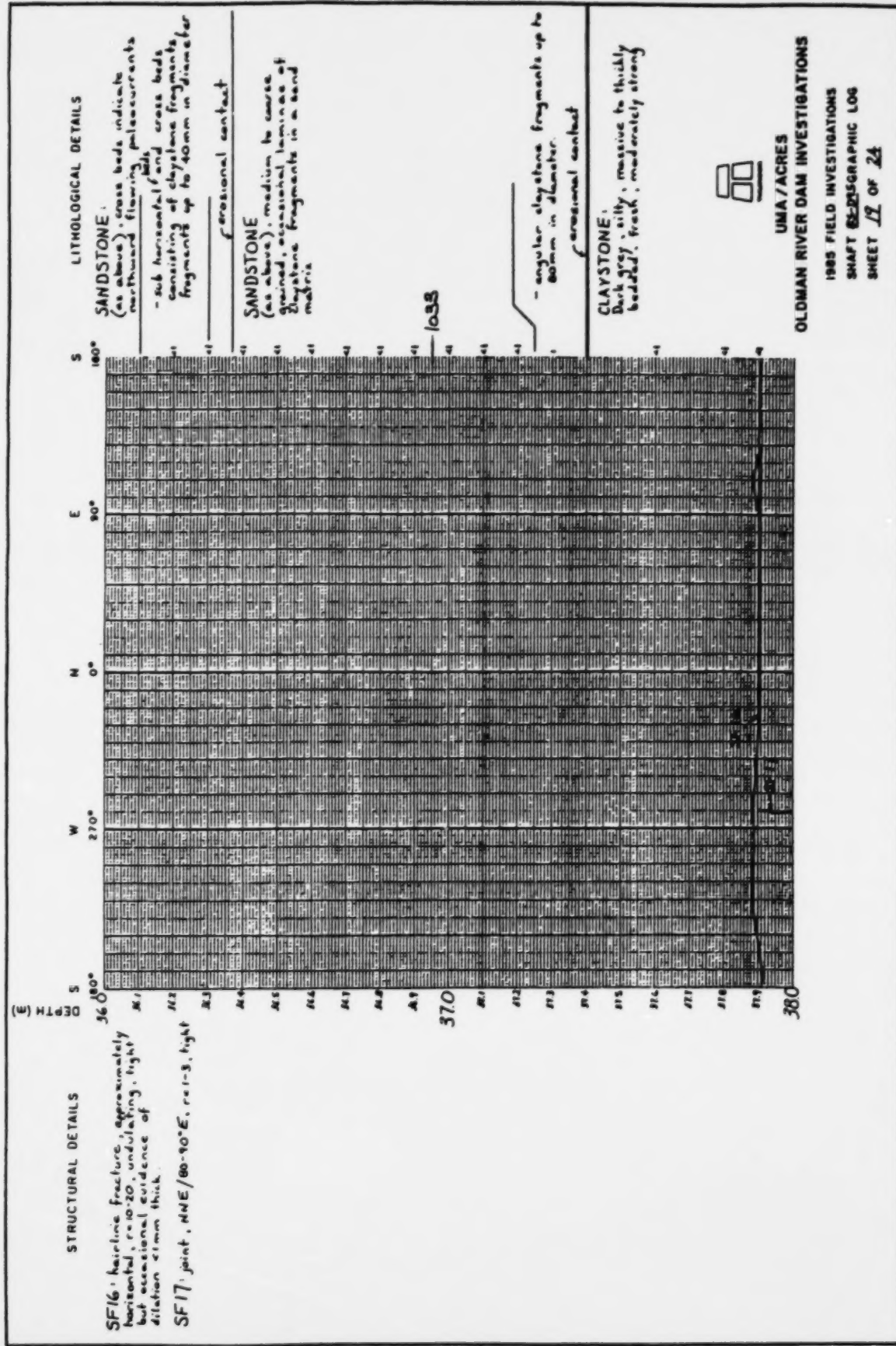


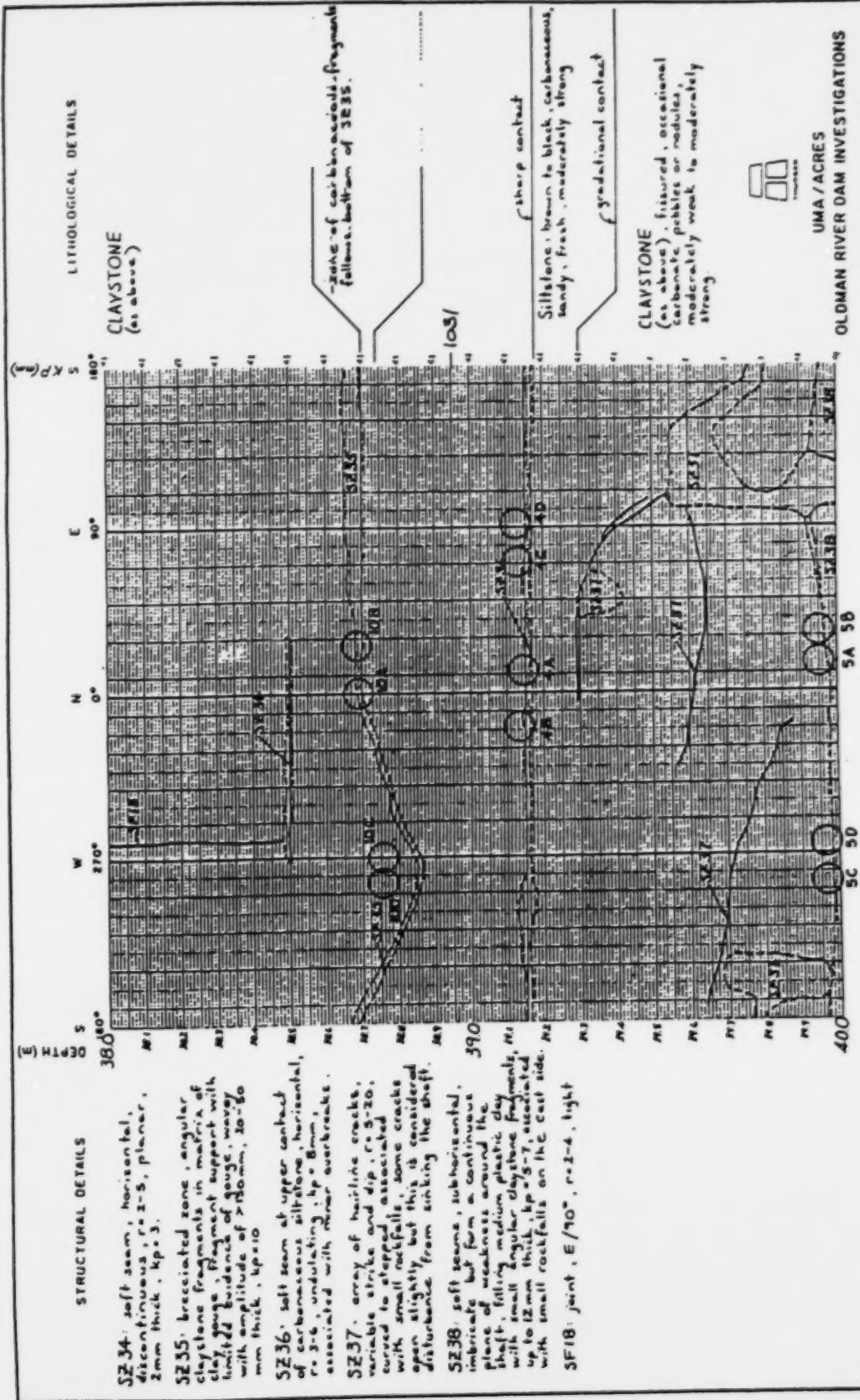
UMA / ACRES

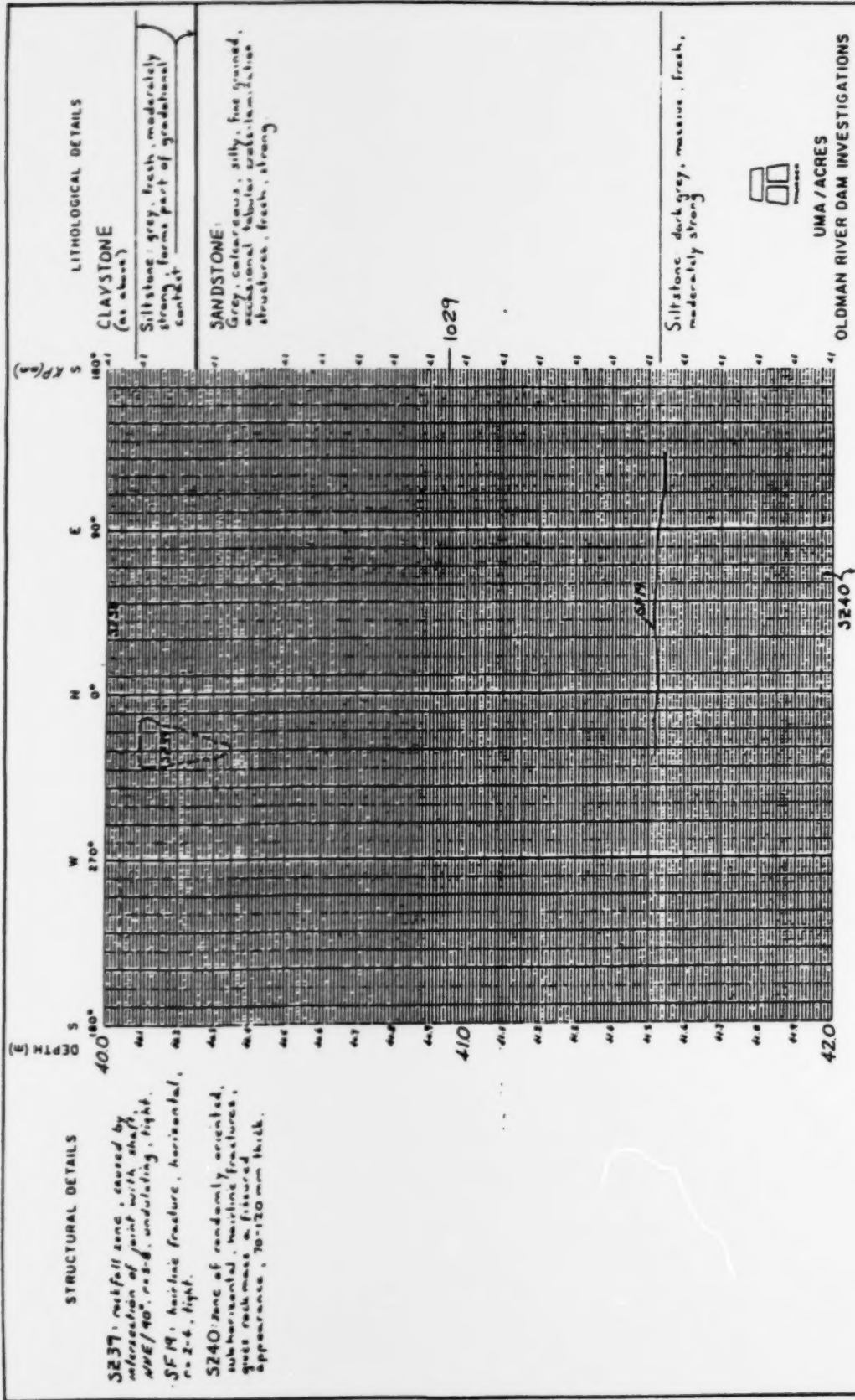
OLDMAN RIVER DAM INVESTIGATIONS

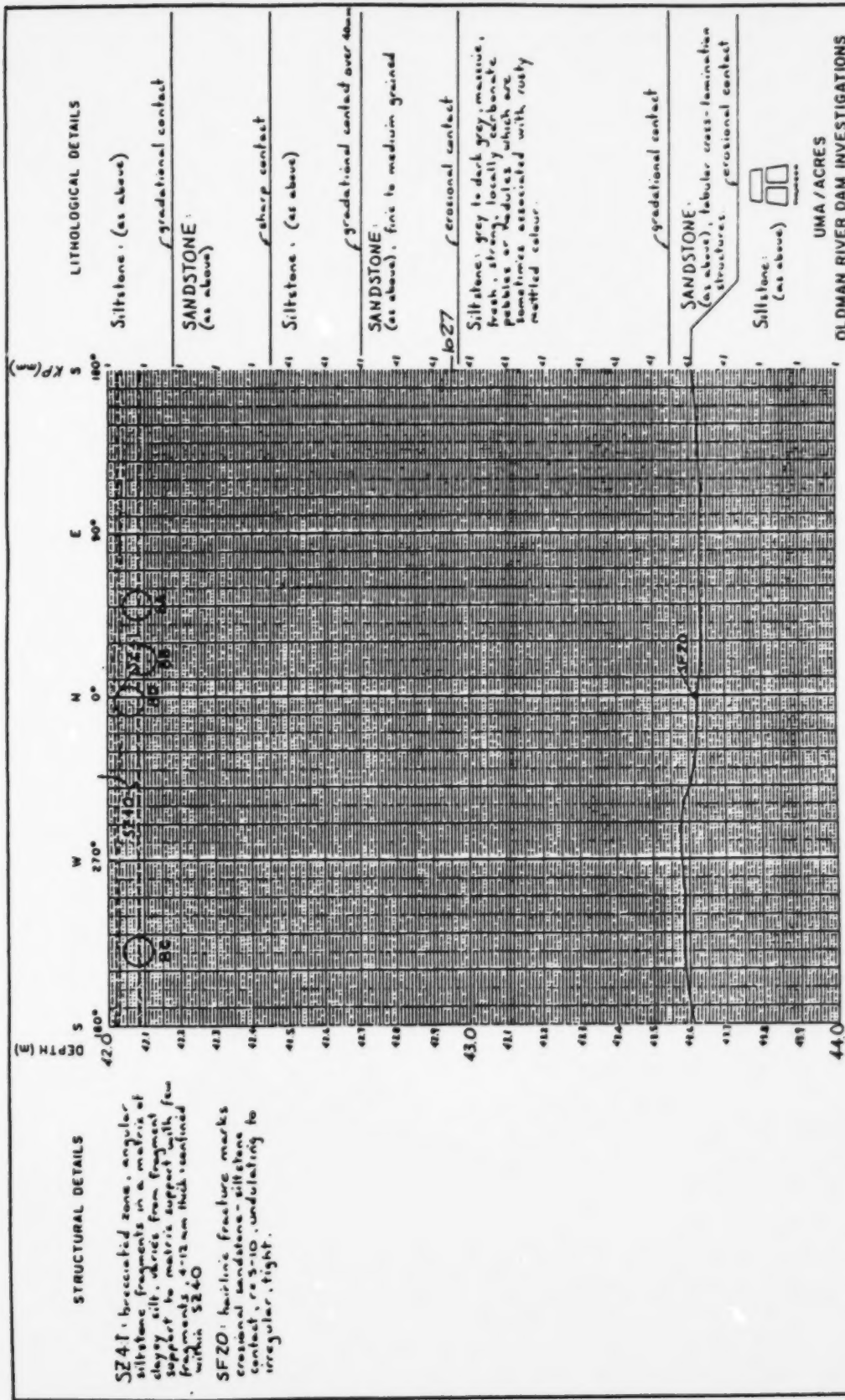
1985 FIELD INVESTIGATIONS
SHAFT BEDROCK LOG
SHEET 18 OF 24

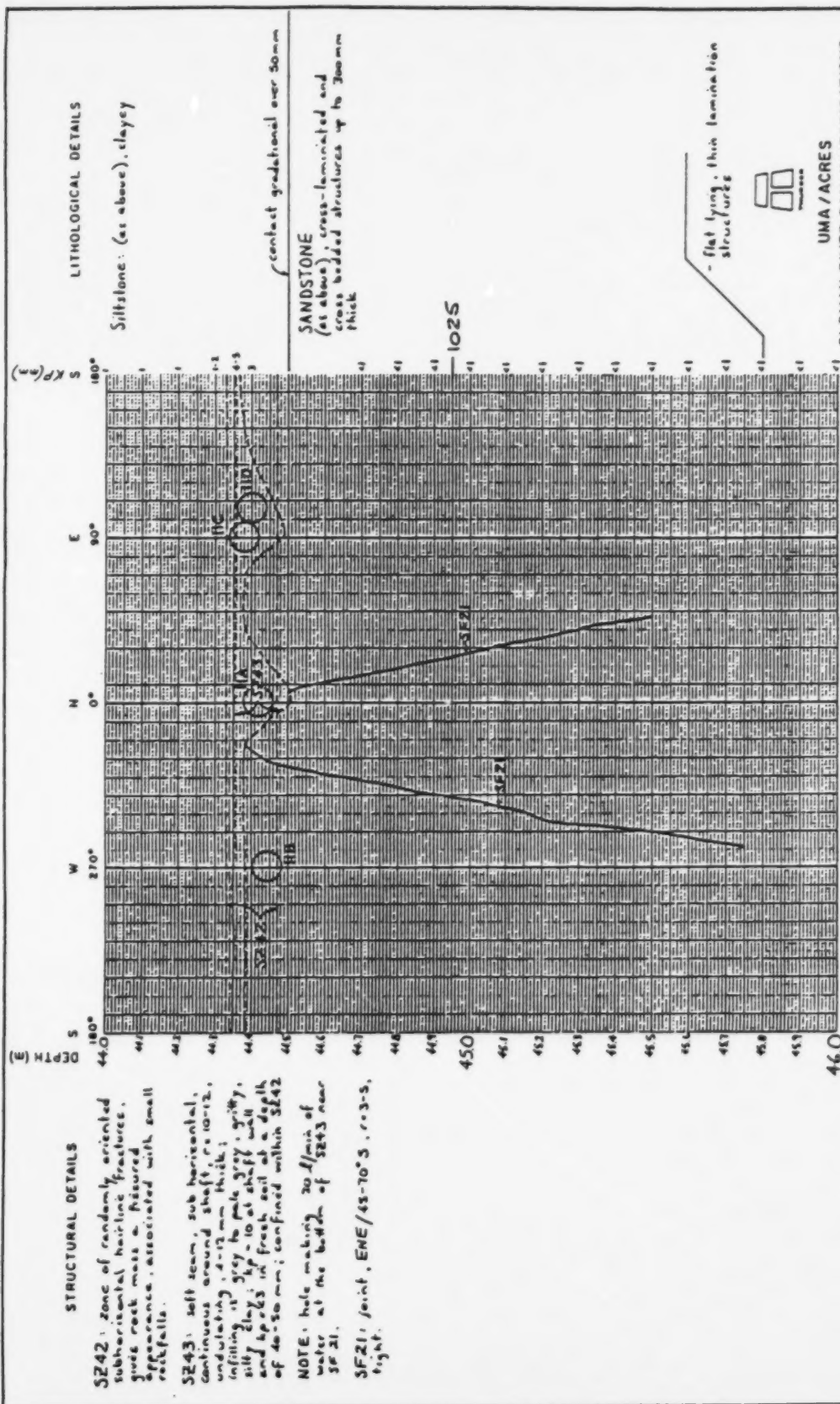












STRUCTURAL DETAILS

SF24: Zone of randomly oriented subhorizontal hairline fractures. Give rock mass a fissured appearance, associated with small rockfalls.

SF23: Left term, sub horizontal, continuous around shaft, c. 10-12, undulating, 4-12 mm thick, infilling of grey to pale grey, silty clay, 4-10 at shaft wall and 4-6 in fresh soil at a depth of 40-50 mm; confined within SF22

NOTE: hole making 30 d/ft of water at the bottom of SF23 near SF 21.

SF21: Joint, ENE/45-70° S, c. 3-5, tight.

LITHOLOGICAL DETAILS

Siltstone: (as above), clayey

contact gradational over 50mm

SANDSTONE

(as above), cross-laminated and cross bedded structures up to 300mm thick

- flat lying, thin lamination structure



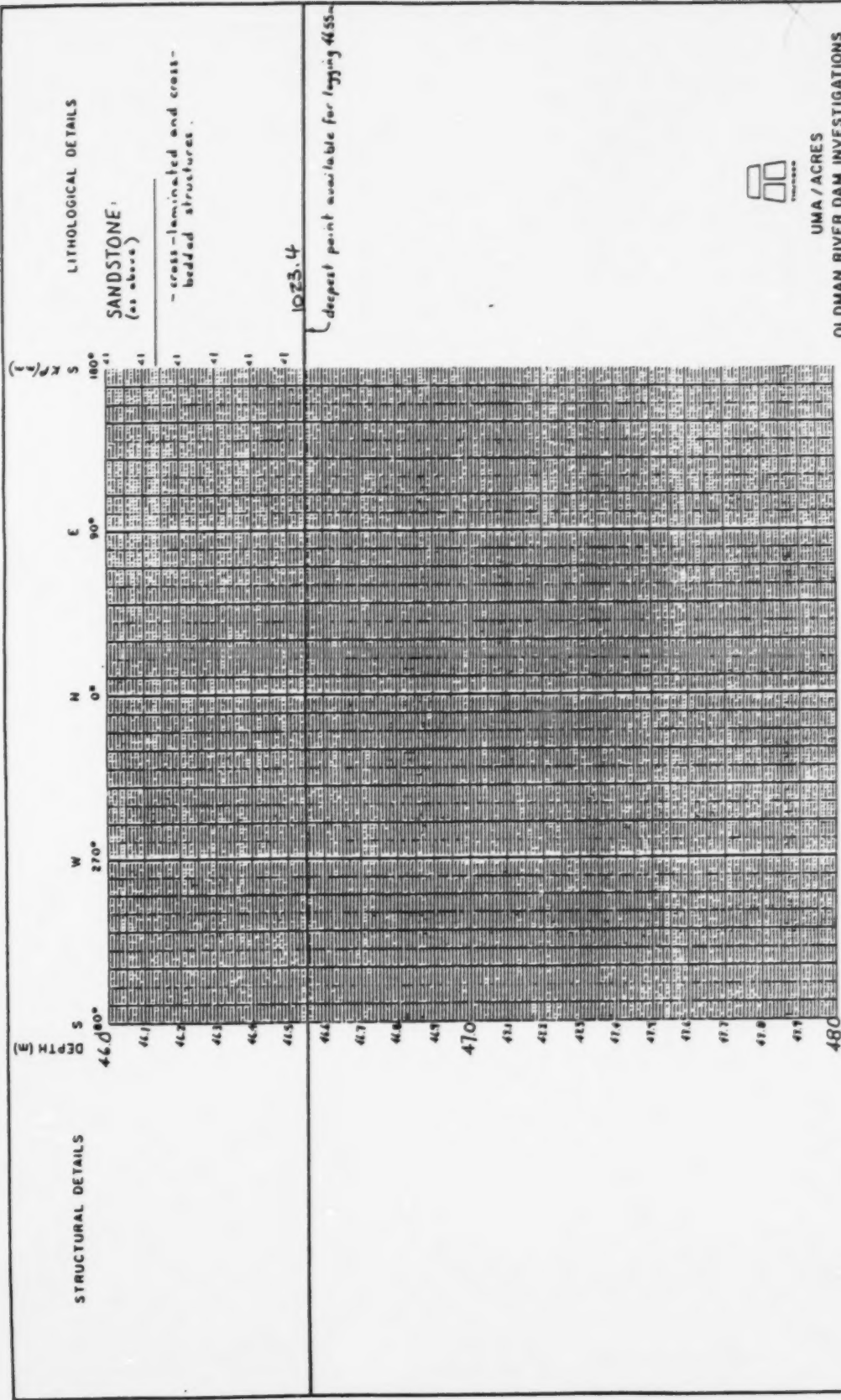
UMA/ACRES

OLDMAN RIVER DAM INVESTIGATIONS

1985 FIELD INVESTIGATIONS

SHAFT 05B5GRAPHIC LOG

SHEET 23 OF 24



LOG FOR
EXPLORATORY SHAFT

S 707

PLATE B-235

OLDMAN RIVER DAM
SHAFT

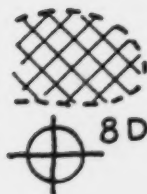
LEGEND:



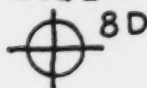
THIN DISCONTINUITY



THICK DISCONTINUITY



OVERBREAK ZONE



CORE SAMPLE LOCATION



CALCRETE NODULES



PHREATIC SURFACE

ABBREVIATIONS:

o/bk

overbreak

sst

sandstone

mcs

silty claystone

Jt

joint

bx

breccia

STRUCTURAL DETAILS

Coordinates
1117 38
1119 38

Ground surface elevation is 1119.38.
Top of casing elevation is 1119.38.
Note is attached to north side of casing at ground surface. All
details are measured below ground surface.

At 10 to 150 mm of bore hole occurs an full circumference except 10 to
15 mm where elevation is 1119.38. Joints are from east coasted,
usually west, with filling of clay and claystone matrix separated in
from adjacent claystone zone. Other short fractures are curved,
rough, dilated 1-2 mm, some filled and some clean.

1. Joints and fractures: type, discontinuous, curved to undulating,
and rough.

2. Upper contact: a sub-horizontal discontinuity, undulating,
type to open 1 mm, possibly clay filled.

3. Sand: probably highly to completely weathered claystone,
composed of moderately weathered angular rock fragments in a
soft silty clay matrix.

4. Continuous claystone zone: characterized by sub-horizontal,
discontinuous, closely spaced, rough, undulating joints and
sub-vertical joints, suggested as SE wall, very weak.

5. Joint: 80° dip, highly undulating, rough, dilated to 150 mm,
trace of soft clay filling, active gray, possibly washed out by
drilling.

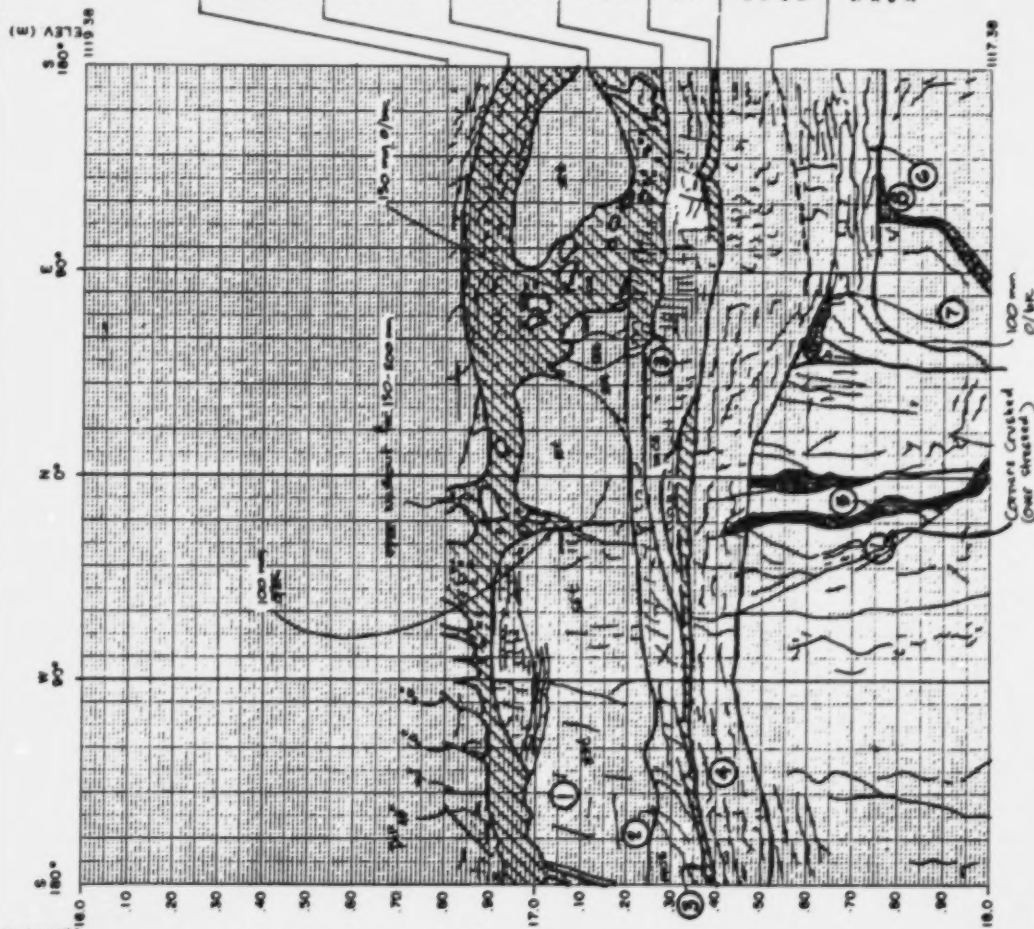
6. Fracture zone: several fractures, sub-parallel, tabularized,
sub-horizontal, locally dilated, from 100 mm, polished brown
clay filling.

7. Highly fractured sandstone: clay filling to soft, wet.

8. Sandstone: 100 - 150 mm, caused by internal fractures in rock.

LITHOLOGICAL DETAILS

NOTION OF CASE: 16.00 m



SANDSTONE: slightly to moderately weathered, carbonaceous
lens-like less than 1 cm thick, medium yellowish brown to yellowish
gray, medium grained, moderately strong to strong, irregular
tight fractures and curved, open joints with increased crushed
material.

CLAYSTONE: slightly weathered with orange iron stained fracture
surfaces, medium yellow brown, weak to very weak rock fragments
in a matrix of wet, very soft clay. Fragments are interbedded
material which has been spalled into adjacent open joints in
sandstone above and below.

SILT CLAYSTONE: completely microfractured, matrix of angular
claystone fragments (average 3 mm, maximum 20 mm) in a matrix of
soft, wet, medium plastic, clayey silt. Fragments are
interbedded, 120 mm northeast on SE and 3 wells at 11.00 m.

SILT CLAYSTONE: moderately weathered, medium brownish gray,
moderately wet, joints and fractures are dilated and very weak,
fractures are fine fissured.

Zone of microfractures, similar to above, glass and small
locally.

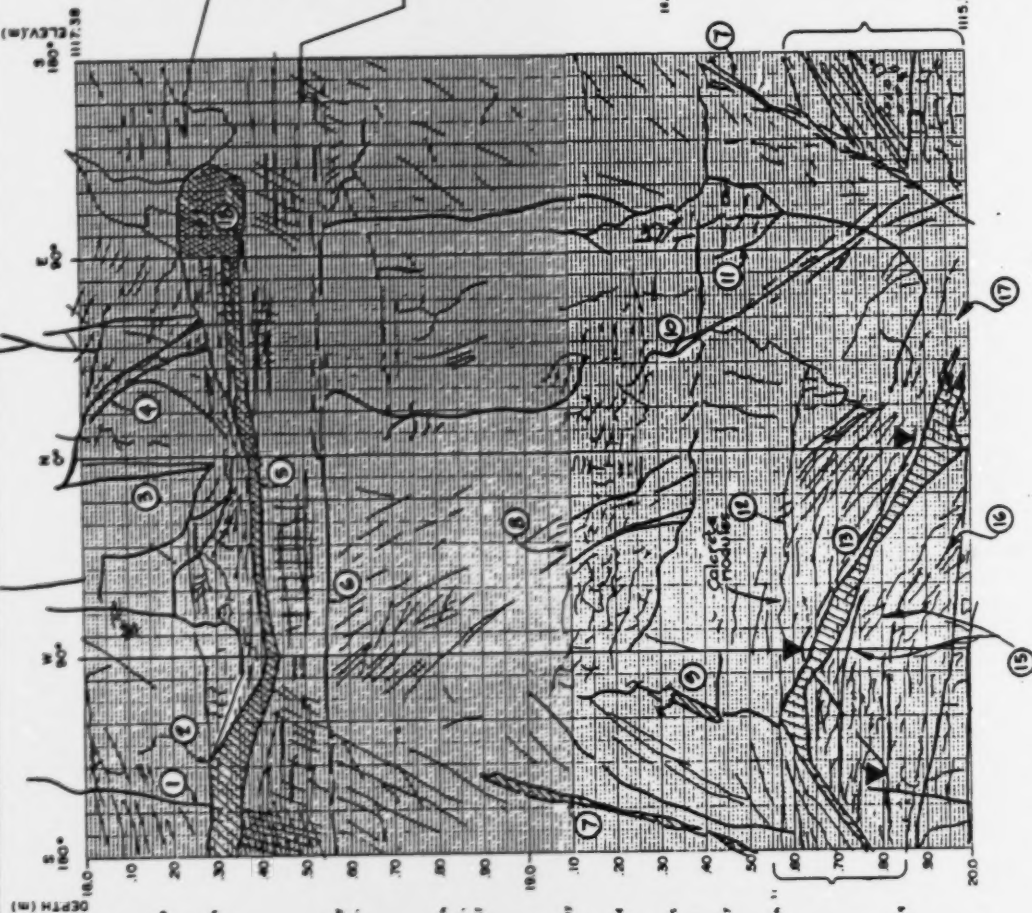
CLAYSTONE: block, very weak, carbonaceous, close joints with
from staining, some possibly undulating or slickensided surfaces
are noted, upper contact sharp, lower contact gradational over
100 mm.

SANDSTONE: moderately weathered, medium yellowish gray to
yellowish brown, medium to fine grained, moderately strong, some
diffuse carbonaceous particles in matrix of sandstone, open
joints noted in dark shaded areas.

ADONIS
CLAYSTONE FROM CASE

SHAFT 5707
SHEET 1 OF 23
LOGGED BY: M. HARTMAIER
DATE: SEPT 10, 1988

STRUCTURAL DETAILS



1. Joint: 45° dip, undulating, rough, from silty, light to silty to 0.5 m.
2. bedding seam: weak, from contact, 0.5 m, weathered yellowish brown clay, silty.
3. Joint: dip 10° E, from silty, tilted to 0.5 m.
4. Joint: dip 10° E, from silty, continuous from 3 (above).
5. Seam: silty, undulating, sub-horizontal, undulating, comprises highly weathered siltstone in a matrix of yellowish brown silty clay. Locally pinches out to a thin, clay weathered plane.
6. Joint: to 3 (above), except below.
7. Seam: undulating, characterized by a zone 10 - 15 m wide with numerous overlapping, undulating, and intersecting fractures. Central 5 m is highly weathered rock fragments in a matrix of clay, yellowish brown, soft, dip 10° E.
8. Joint: vertical, clay filled, open 2 - 5 m, soft, plastic.
9. Joint: tilted 10 - 20 m, open, no filling, truncated by sub-horizontal discontinuity.
10. Joint: partially weathered, tilted 5-10 m, becomes a clayed series of 1 - 2 m clay filled fractures below 10 m.
11. highly weathered seam: 2 - 5 m weathered siltstone fragments in a matrix of soft silty clay.
12. Seam: 1-5 m thick, clay cased, adjacent rock is closely fractured.
13. Silty clay seam: medium to high plastic, soft, medium yellowish brown.
14. Bedrock: 15.5 - 16.5, 10 m deep, on a side.
15. Seam: 5 m, clay and rock fragments.
16. (bedrock, sub-parallel). Fracture pattern consisting along sub-horizontal seams.
18. highly weathered rock: soft silty.

LITHOLOGICAL DETAILS

SILTSTONE (Continued): As above except continuous laminae are well defined and dipping at 10-15°. Lower contact is closely jointed and fractured.

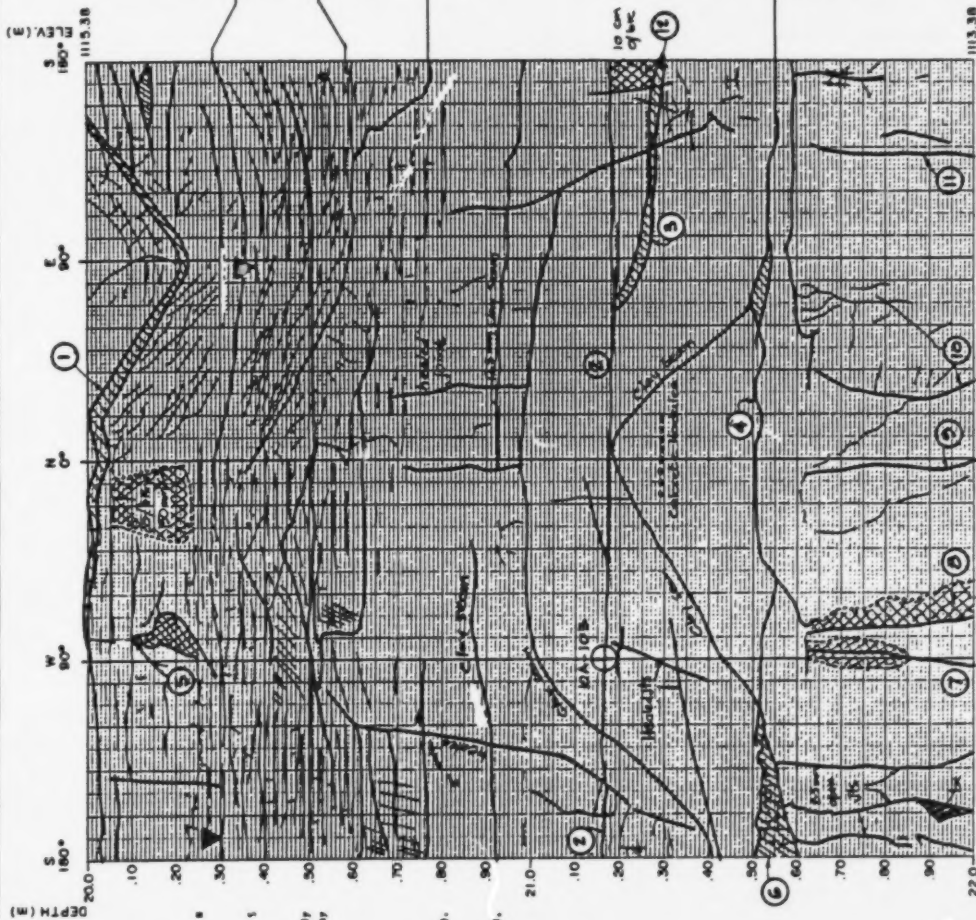
Bedded SILTSTONE and Clay SILTSTONE: undulating to slightly weathered, medium brownish gray, micaceous, silty, silty, irregular fractures: cased with iron scales, locally extremely closely jointed or fractured with silty clay matrix. Lenses of basalt, clayey joints, suggested claystone in a clayey siltstone matrix. Near contact is sharp, irregular, lens material is situated into sandstone joints. Lower contact is locally defined by a thin line, or clay grades into less fractured rock through a series of small, sub-parallel fractures.

Clay SILTSTONE: highly weathered, medium yellowish brown, fine grained, very weak to weak (silty), locally very closely jointed, all discontinuities are tight and sealed with iron scales, joints are generally nearly horizontal.

16. CLAYSTONE: undulating to highly weathered, very weak, slightly fractured, horizontal discontinuities on multiple fracture surfaces.

CLAY SILTSTONE: disturbed, fractures are all tight and cased with iron scales except as noted.

STRUCTURAL DETAILS



1. Clay seam with rock fragments: soft, wet, yellowish brown.
2. Clay seam: 2 - 5 mm, horizontal, covered 50 mm overbreak on a wall.
3. Clay seam: 10 - 15 mm, green like several thin fractures on S wall.
4. Clay seam contact: 5 - 10 mm thick, margins very closely fractured and weak, thickest where intersected by other clay seams. Contains silty clay: soft, wet, yellowish brown.
5. Overbreak: 200 - 300 mm, along joint dipping up to W.
6. Brecciated rock: clay coated.
7. Joint: sub-vertical, dilated 5 mm, some overbreak, unmineralized.
8. Overbreak: 100 mm, along sub-vertical joint, dip 45°, curved, rough.
9. Joint: open 2 mm.
10. Joint: curved, open 2 mm, from outcrop casing.
11. Joint: planar, open 2 - 5 mm.
12. Weak zone: 15 mm of clay and crushed silty claystone.

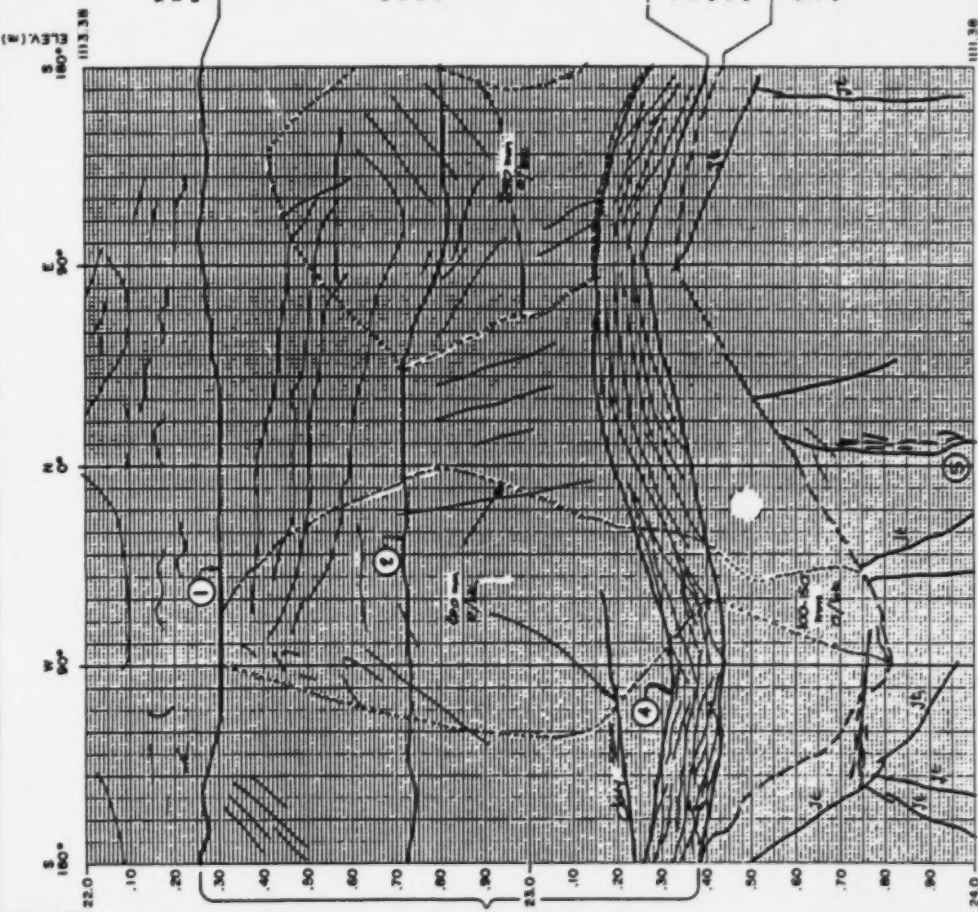
LITHOLOGICAL DETAILS

- SILTSTONE:** slightly weathered, yellowish brown, fine to medium grained, very weak, slightly fractured.
- Water seepage below 20.3 m.
- CLAYSTONE:** completely to slightly weathered, dark grey, slightly fractured, intermass fractures at 10 mm spacing, from oxide coating.
- CLAYSTONE:** slightly to moderately weathered, dark grey, fine grained. Fractures mainly sub-horizontal and clay coated, 0.5 to 1.0 mm, discontinuous, from oxide coating, slight, weak. Lower contact is gradational with discontinuous horizontal sand seams.
- SILTSTONE:** moderately weathered, medium yellowish brown, weak. Fractures generally light and healed with iron oxides. Zone of calcareous nodules 2 ft. 20 m, to 20 m diameter.

SANDSTONE: slightly to moderately weathered, medium brownish grey, medium to fine grained, moderately strong to strong, large type cross bedding lamination from 21.55 to 25.10. Joints are open, sub-vertical at west, others are light, rough, irregular.

STRUCTURAL DETAILS

1. Contact: thin clay mixed zone, less than 0.5 m, slightly rough.
2. Clay zone: within 2 - 5 m, within 10 m near intersection with shear, major northeast below this zone.
3. Disturbed rock: predominantly fractures are sub-horizontal, continuous, undulating, clay coated. Secondary joints and fractures are multi-directional, iron banded, irregular.
4. Lower contact of claystone: disturbed by very closely spaced multi-directional (but generally subparallel to contact), slickensided fractures, iron scale on surface.
5. Joint: dip 65°, rough, undulating, iron scale.



LITHOLOGICAL DETAILS

Silty claystone: slightly weathered, medium granular gray, weak, iron scale on tight fractures, penetration of iron scale far up to 10 m.

Claystone: fresh jointed, dark gray, very weak; highly fractured, jointed, and layered; softened with water slaking, lower contact is well defined and consists of numerous closely spaced sub-parallel fractures, usually clay coated.

Silty claystone: slightly weathered, medium granular gray, weak, 10 - 20 m of penetrative weathering along tight joint (wide dislocation), softened by water, lower contact with siltstone (is gradational), usually expressed by iron scale or a very tightly healed irregular joint.

Siltstone: slightly weathered, medium granular gray, strong, 10 - 20 m penetration of iron discolouration on joints. Siltstone often are tight.

STRUCTURAL DETAILS

Pd, 100 = Pd, 50: all joints are tight, heated, turn on the oil flow.

1. Slip clay seal: medium plastic, medium yellow brown, soft, wet. average 10 - 15 mm, sections 50 mm thick, walls are decorated and very used.

2

2. Personnel and teams within the group.

6. met tons of lower contact: rock fragments, slightly weathered, 20 - 30 mm diameter, in a matrix of silty clay, medium yellowish brown.

3. Notes: 1. Advertising vertical labels, rounding off and and, from costed, 90 - 30 mm of uncoated.

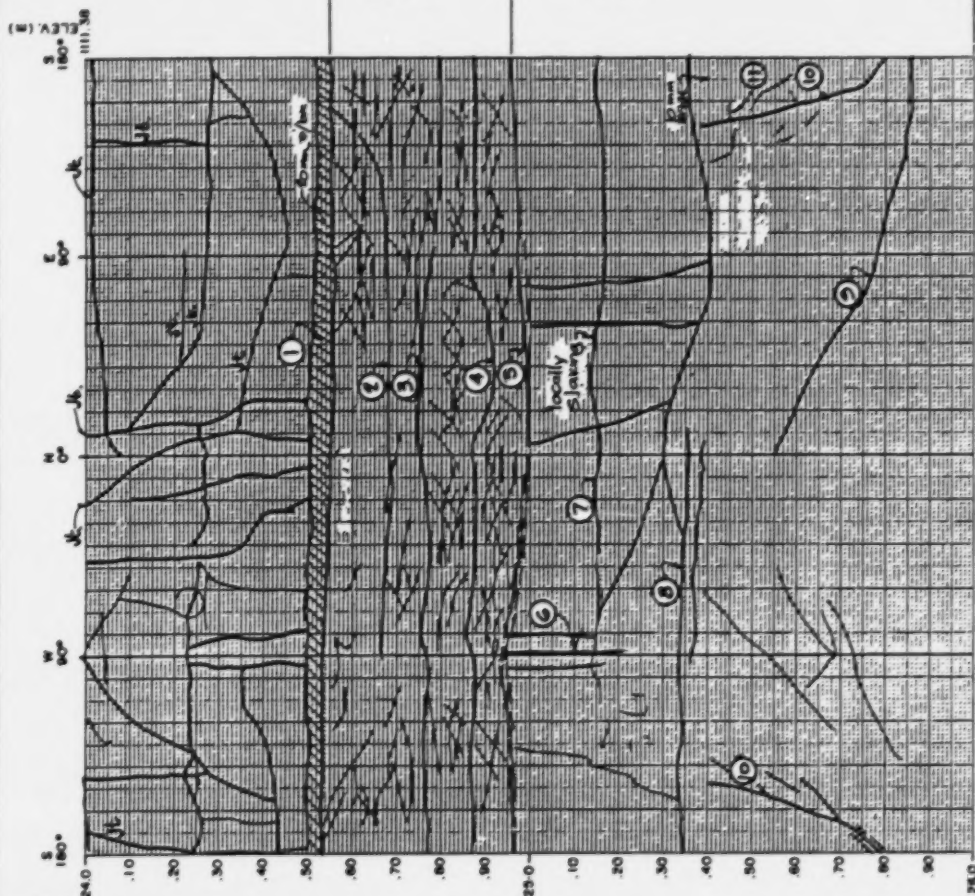
2. **Notes:** **Investment**, **light**, **iron oxide coating**, **silicon dioxide coating**, **insulating**, **insulated**.

8. Notes: see transcript, typed, sorted, transcribed, collated, descriptive numbering of 10 - 122 ms, Locality 10 - 30 ms at southeast.

Address: 81901, New York City, New York 10024, USA
New York City

14. *Intet*: curved, rough, light, translucent, elong. W.

11. Chestnut: 100 cm, curved by internal joints.



LITHOLOGICAL DETAILS

016,09,00000 : 00 choro

CLAYSTONE: slightly weathered with iron oxide discoloration penetrating 10 mm from fractures, medium greenish gray, med. to coarse-grained, locally claystone surrounded by web seams 5 to 10 mm thick, little or no weather near contact.

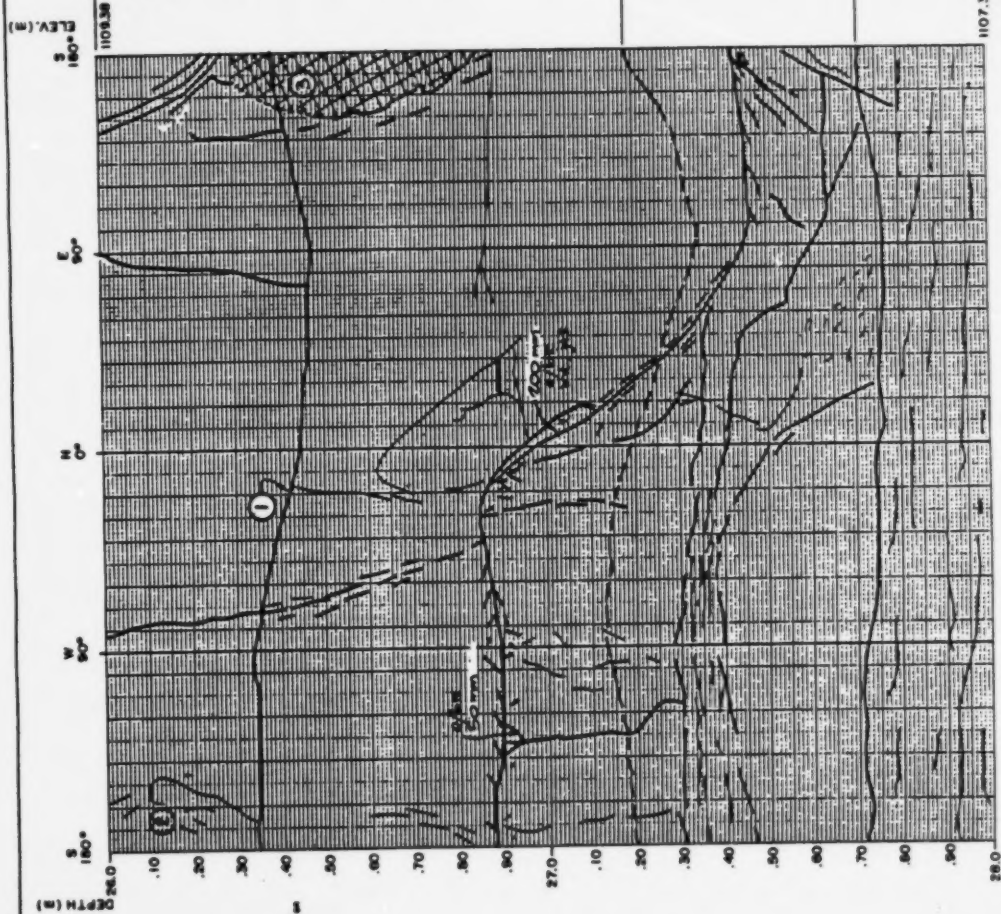
HAIR: Fresh joined to slightly weathered with fine white branching and discolouration penetrating up to 10 cm. Slightly mottled, main greenish grey, turning to uniformly strong grey claystone from 24.15 - 26.36, uniform. Joints are tight, from related.

19.00 - 20.00: Calcate medals, scattered, 10 on average
11 meter.

1100.30

STRUCTURAL DETAILS

LITHOLOGICAL DETAILS



SILTSTONE: slightly weathered when 100 m of dislocation on joints show; diffuse, trough-shaped, dark lenticles, curved beds, and other slump structures; medium greenish gray, fine grained, massive, strong to very strong.

SILTSTONE and Sand SILTSTONE: fresh jointed to slightly weathered, from side penetrates 2 - 5 m from joint, into 1 - 2 m horizontal lenticles, some slump structures, medium greenish gray, fine grained, moderately strong.

CLAYSTONE: fresh to fresh jointed, from side on fractures, medium greenish gray to dark gray, very wet, swelling 20 - 30 mm, softens, slaking, irregular sub-horizontal fractures and clay seems to melt.

1107.36

ADCO
OLDHAM INVERT DASH

SHAF 3707
SHEET 6 OF 23
LOGGED BY: M. HARTMAN
DATE: SEPT. 11, 1988

LITHOLOGICAL DETAILS



- CLAIMANT :** WILLIAM J. WILSON

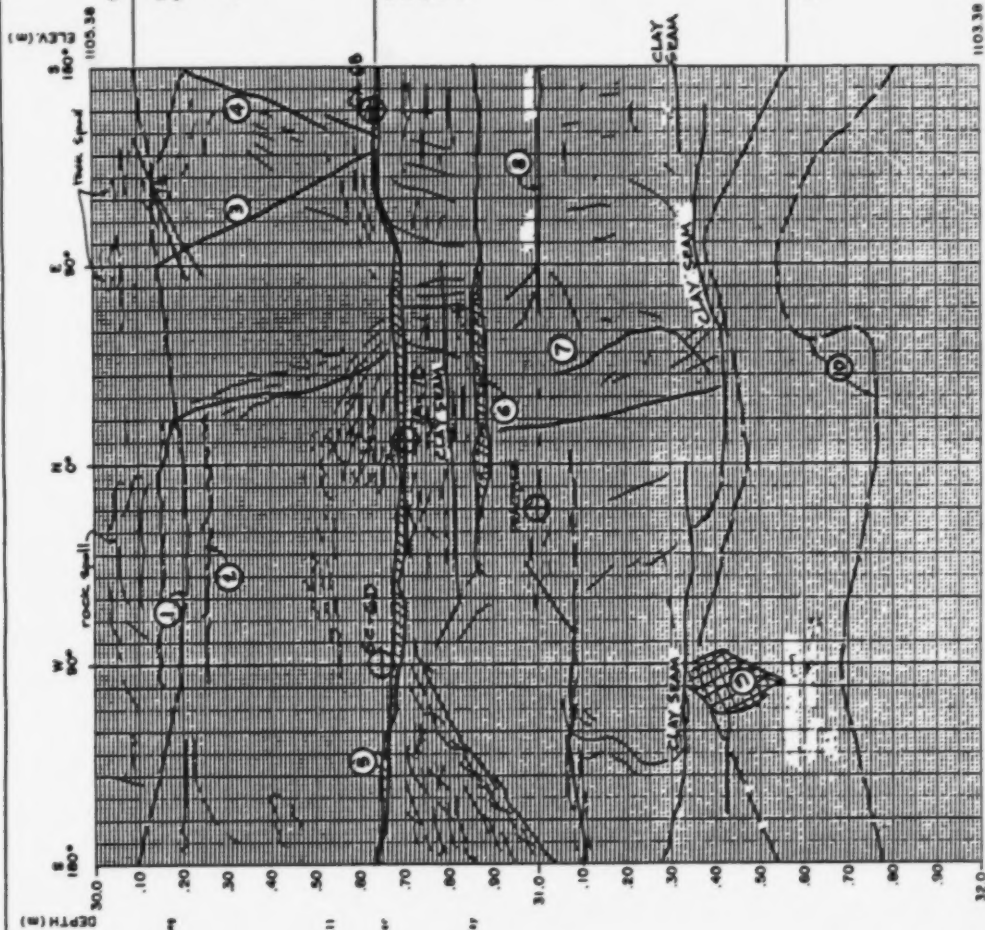
SLIPPER: Fresh joints to slightly weathered, thickly bedded, with horizontal cross bedding laminae, upper grayish green, very strong, slightly jointed.

Slip Claviform: Fresh to freshly leached, dark greenish gray, weak, locally overcast, upper contact gradational.

1105.30

STRUCTURAL DETAILS

LITHOLOGICAL DETAILS



1. Contact: gradational, not a discontinuity, minor spalls along contact.
2. Mud seam: a series of overlapping discontinuities.
3. Joint: dip 90°, glass, rough, tight.
4. Joint: dip 60° to W, glass, rough, tight.
5. Clay seam: 10 - 30 cm, undulating, variable thickness. Wall rock: foliated parallel to seam, very weak.
6. Clay seam: 40 cm, pinches out to thin, clay covered shear joints.
7. Spalling: fractures are conchoidal, close.
8. Clay seam: 10 - 30 cm, slightly fragmented claystone in a clay matrix, locally a joint: thin, clay coated.
9. Bedrock: 40 cm, along intersecting joint.
10. Contact: gradational, 10 - 30 cm overwash.

CLAYTIME: continue

SILURINE: fresh, thinly laminated bed massive, medium grayish brown, strong, tightly jointed.

CLAYTIME: Fresh, medium granular gray, weak. Fractured: blocky 20 - 40 cm spacing, tight. Several major discontinuous clay seams: pinch out to thin shear joints, overstepped locally, weak, joints dilating. Gradational upper and lower contacts.

SILURINE: see description on next page

1103.30

LITHOLOGICAL DETAILS



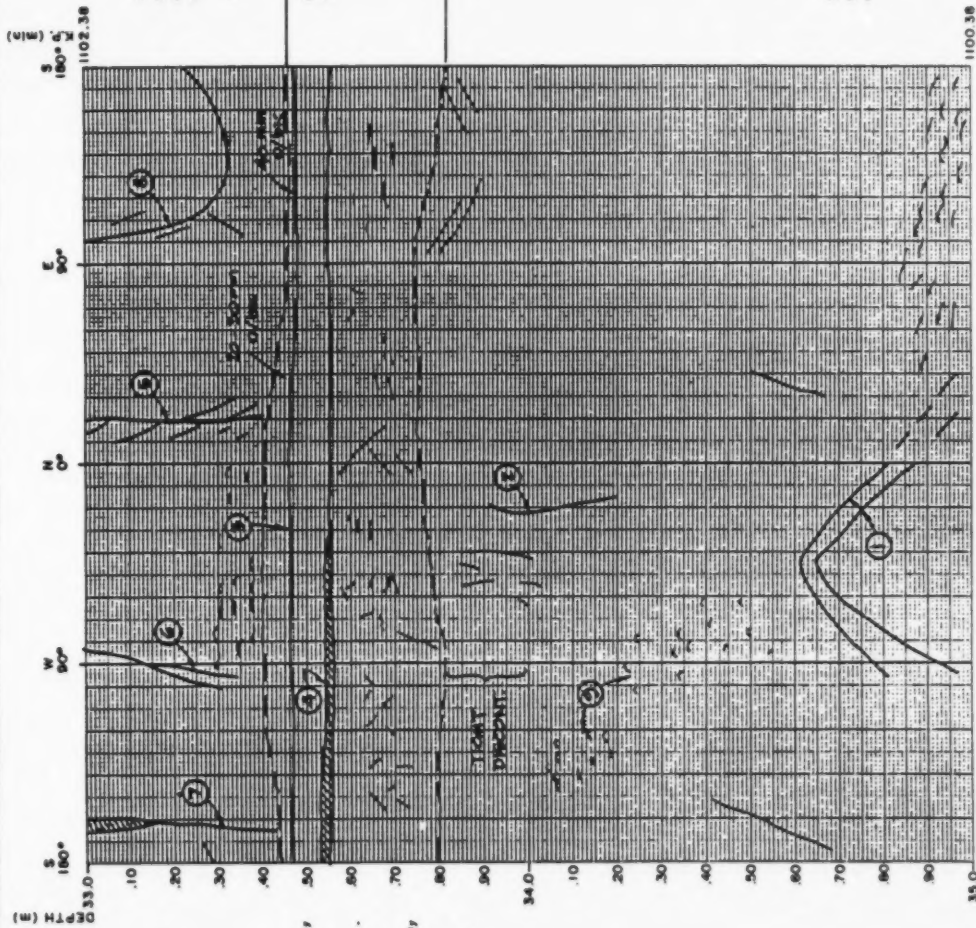
SILTING: slightly weathered, thickly bedded, uniformly strong to very strong, lower contact gradational.

22.90 - 33.60: current bedding truncations.

Abaco
SHEETS
SHEET 9 OF 23
LOGGED BY : M. HARTHAUER
DATE : SEPT. 7, 1966

STRUCTURAL DETAILS

LITHOLOGICAL DETAILS

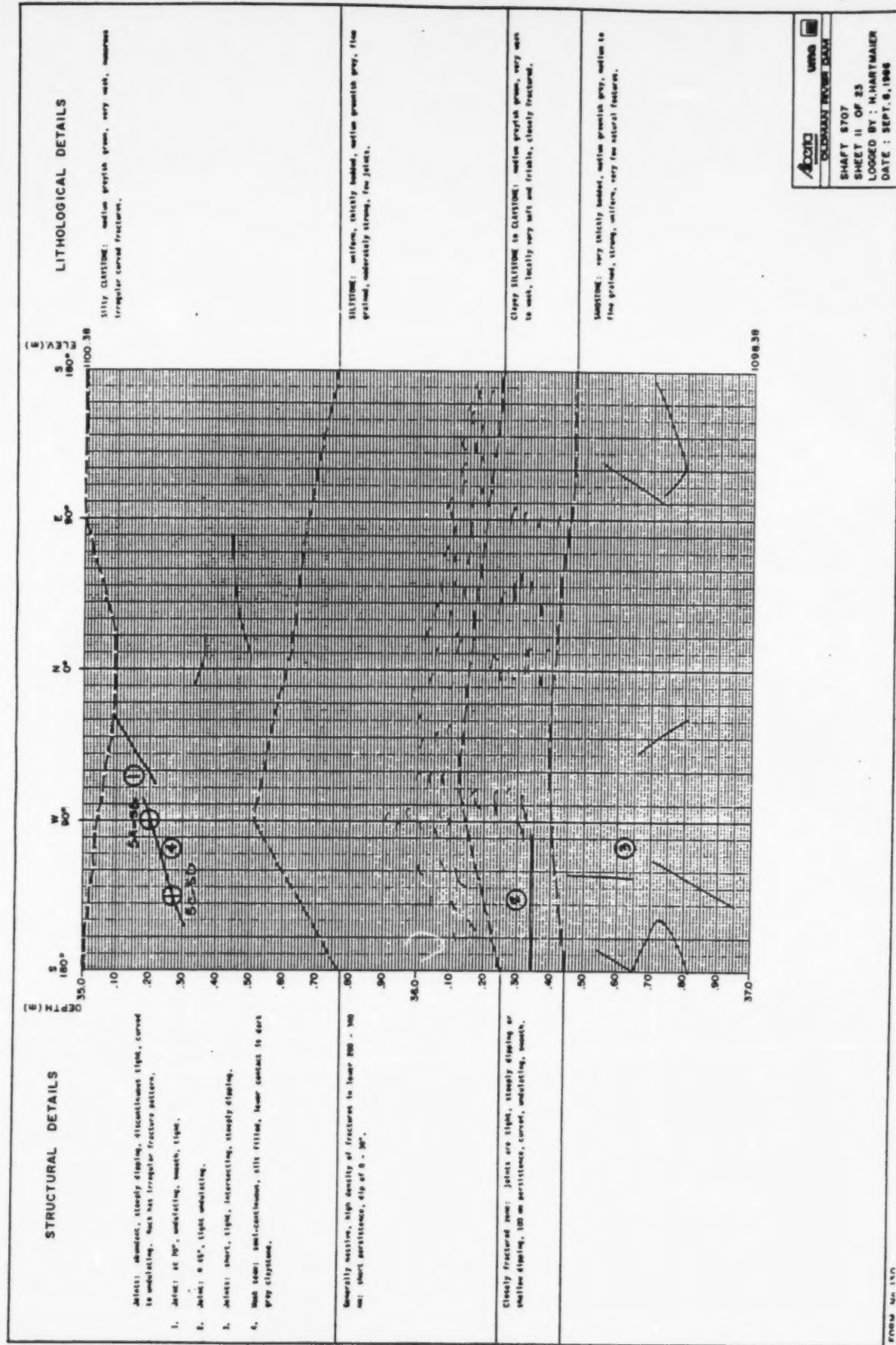


Silty sandstone: upper contact gradational, slightly weathered with up to 100 mm penetrative weathering, locally bedded with dark current bedding laminae 8 - 10" dip, medium grained grey, fine grained, strong, sub-vertical joints.

CLAYSTONE: fresh, medium greyish green to dark grey, weak, friable, slickensided, closely fractured.

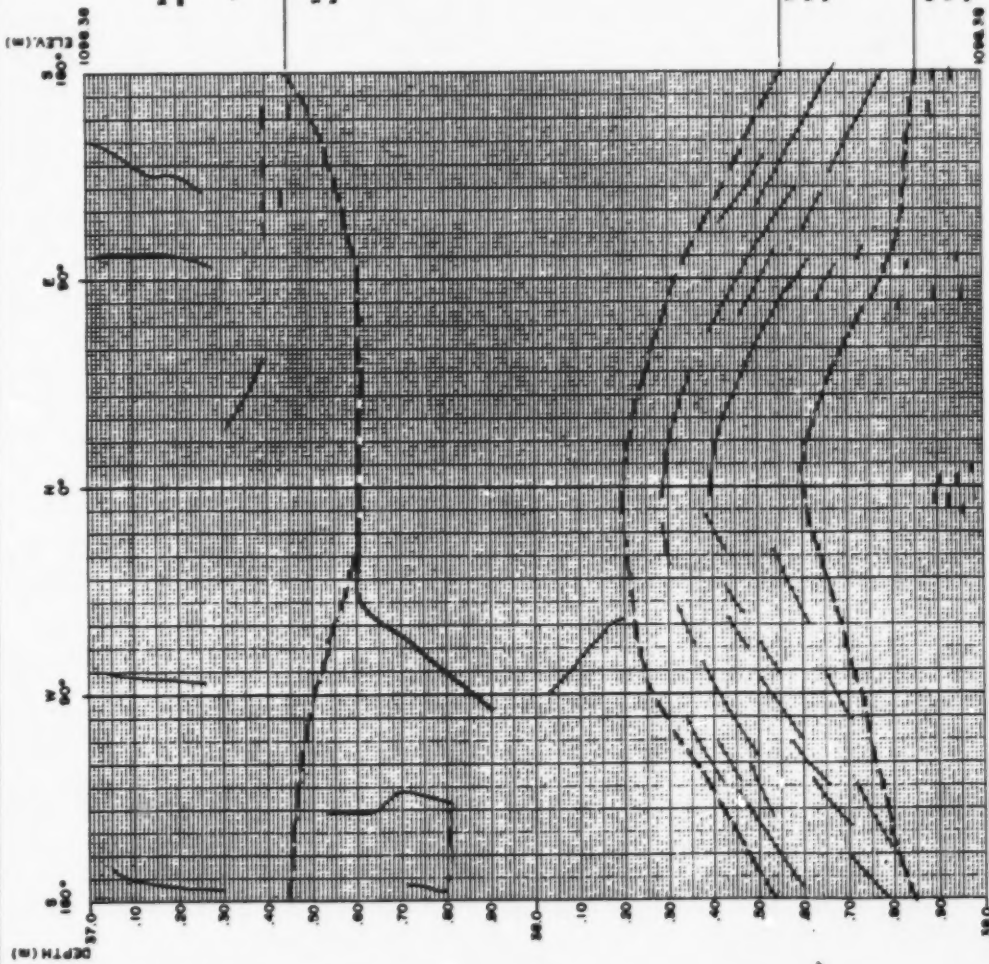
SILTSTONE: massive with some very thin bedding, medium grained grey, strong, uniform, most fractures are open, sharp floor contact.

- 2 Joints: Sub-parallel to 10° dip, smooth, tight, from silty sand.
- Joint: Sub-parallel, curved, smooth, tight, from silty sand.
- Seam: hairline, tight.
- Claystone seam: 10 mm thick, plastic when wet, weak.
- Joint, sub-parallel with splays, curved, rough, tight, locally open 10 mm, penetrative weathering 10 - 100 mm.
- Joint: Sub-parallel, rough, tight, penetrative weathering 10 - 100 mm.
- Joint, sub-parallel with splays, curved, rough, tight, locally open 10 mm, penetrative weathering 10 - 100 mm.
- Joint: continuation of (5), splays, from silty sand, dip at 60°.
- Fractures: short, 20 - 30 mm long, tight.



STRUCTURAL DETAILS

Joints: several, short, light, undulating, smooth.
Fractures: random, short, light.



Fractures: discontinuous, parallel, sub-horizontal or sub-vertical, average 1 m spacing.

LITHOLOGICAL DETAILS

Sample: 10 above, lower contact granitic over 100 - 200 m.

Silt claystone: medium granitic grey, strong, well foliated, breaks into a group well, very fine natural features.

Bituminous silty claystone: medium greyish green, very weak, soft when wet, very closely fractured, friable, fractures coated with clay.

Clayey sandstone: medium granitic grey, fine to medium grained, strong to very strong, uniform, closely jointed and fractured to upper 100 - 200 m strong contact.

Adopt
COLUMBIA UNIVERSITY

SHAFT 5707
SHEET 12 OF 23
LOGGED BY: N. HARTMAIER
DATE: SEPT. 8, 1988

STRUCTURAL DETAILS

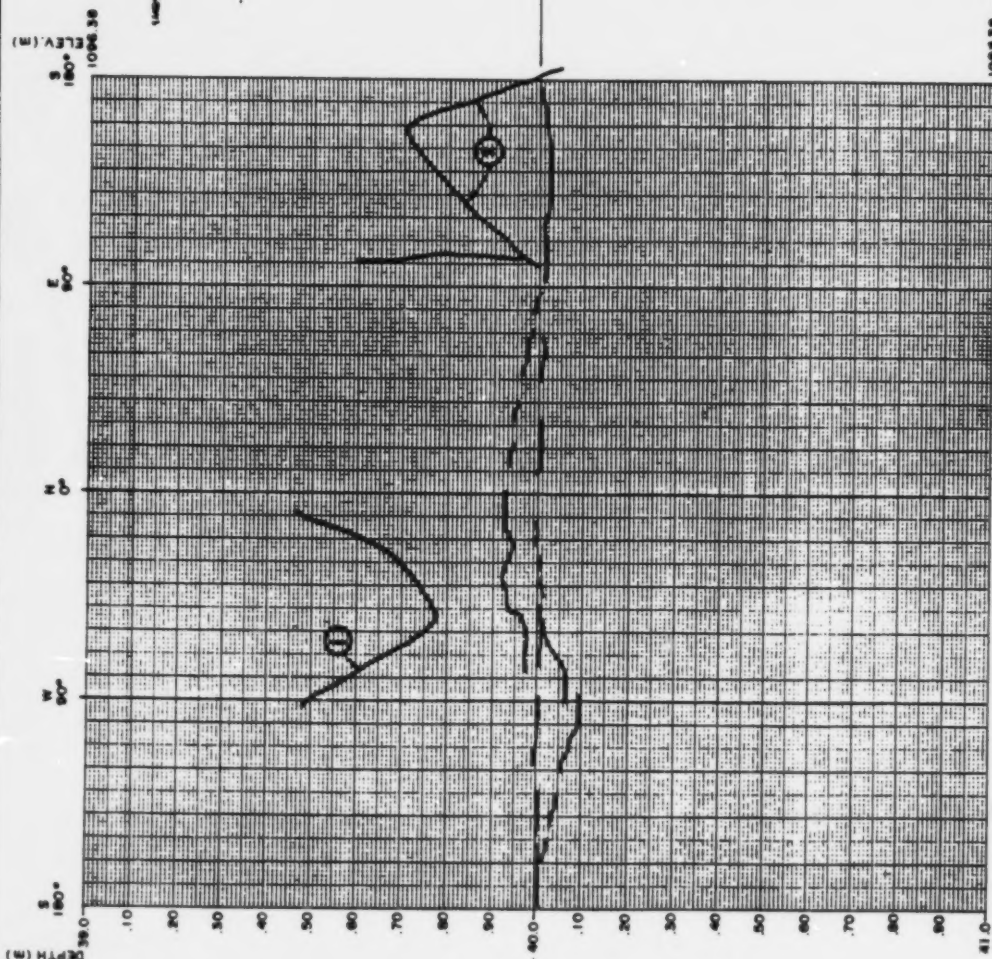
- 1. Joints: 0 90°, radiating, rough, tight.
- 2. Joints: 0 90°.

Closely joined rock, possibly a weak zone.

SEE NEXT SHEET FOR DETAILS

LITHOLOGICAL DETAILS

140517M: 05 above.

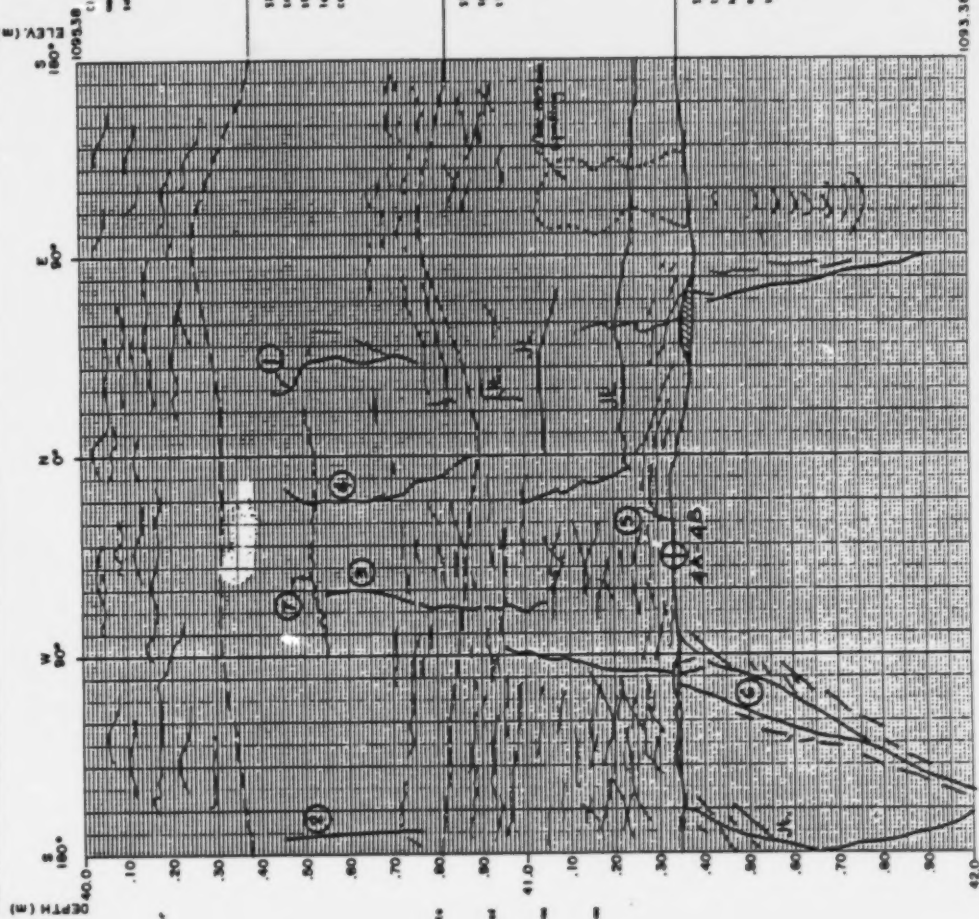


SEE NEXT SHEET FOR DETAILS

Adopted
SLOPE
SLOPE

SHEET 2707
SHEET 13 OF 23
LOGGED BY: H. HARTMAIER
DATE: SEPT. 8, 1966

STRUCTURAL DETAILS



no pronounced fractures; rock appears tight, but is spalling over full circumference.

1. Joint: curved, sub-vertical, from side, tight.
2. Joint: undulating, tight, sub-vertical, from side.
3. Joint: undulating to curved, sub-vertical, tight, from side.
4. Joint: curved, tight, sub-vertical, from side.

Joints: sub-horizontal, curved, well-continuous, parallel to contact.

5. Unit seam: from contact, adjacent rock is weak and fractured parallel to contact. Disited to 25 m where heavily sheared.

6. Joint: splined, dip 45° S, planar, tight, from side, 10 m penetrative dislocation.

7. High zone: several overlapping curved fractures, up to 50 m each, tight.

LITHOLOGICAL DETAILS

CLAYEY SILTSTONE: Freshly jointed with iron oxide on fractures, medium brownish grey, strong to very strong, closely jointed with sub-horizontal fractures spaced approximately 10 mm, tight.

SILTSTONE: Freshly jointed with iron oxide on joints, off-white to light brown, strong to very strong, occasional silty sand to 10 mm near lower contact, tight joints, preferential upper and lower contacts.

SILTY CLAYSTONE: Fresh, dark brownish grey, moderately strong, spalling. Fractures: numerous, discontinuous, sub-horizontal, tight, healed with iron oxide.

SANDY SILTSTONE: Fresh to freshly jointed, massive with trough-shaped curved indentations; poorly developed, sub-horizontal, medium brownish grey, fine grained, without, iron oxide on joints, 100 mm penetrative dislocation on sub-vertical fractures.

Aceto LITHO

ORDINARY REVERSE DATE

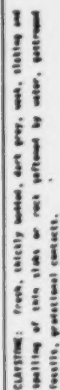
SHAFT 870F

SHEET 14 OF 23

LOGGED BY: N. HARTBAUER

DATE: SEPT. 13, 1988

LITHOLOGICAL DETAILS



Clayey siltstone: fresh, uniform, dark greenish gray, fine grained, moderately strong.

10001-500

Ready 20170000: 00 above.

1. Joint: sub-vertical, strikes EW, unroofing, tight, from outside.
2. Joint: sub-vertical, strikes SE, planar, rough, tight, from outside.
3. Unit contact: stepped, discontinuous joints with weak walls, from outside.
4. Overlook: 100 m, spalling.
5. Overlook: 50 - 30 m, spalling.

Joints are generally tight, curved, from outside.

Fractures: abundant, curved, short, conchoidal, splitting.
 Joints: rare, very short, tight, close.

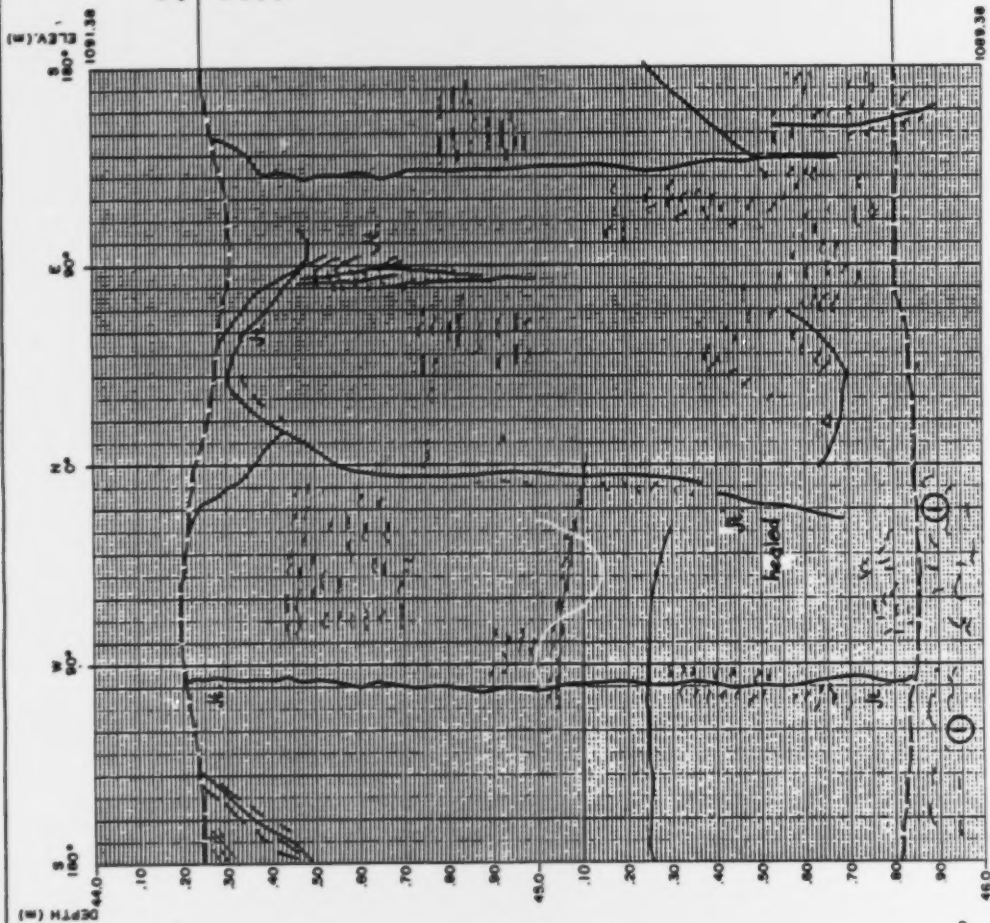
Fractures: abundant, tight, wavy, tight. Joints: rare, tight, curved, close.

Aberta
uma nova forma de pensar

SHAFT 3707
SHEET 15 OF 23
LOGGED BY: N. HARTMAIER
DATE: SEPT. 13, 1988

STRUCTURAL DETAILS

LITHOLOGICAL DETAILS



Notes: sub-vertical, curved, tight, from about 50 - 100 m penetrative weathering.

1. Break: 20 - 50 m, spalling.

Silly CLASSIME: at about, sharp lower contact is not a discontinuity.

Silly SILTSTONE: slightly weathered with up to 100 m penetrative dislocation around sub-vertical fractures, uniform with poorly developed isolated bedding, uniform greyish green, fine grained, strong to very strong.

Silly CLASSIME: fresh, uniform, dark greenish grey, very fine grained, weak to moderately strong.

Fractures: sub-horizontal, short, curved, tight, close, 20 - 50 m long; some close, conchoidal fractures.

GEOLOGICAL SURVEY OF CANADA SHAFT 5807 SHEET 18 OF 23 LOGGED BY: H. HARTMAN DATE: SEPT. 13, 1966	

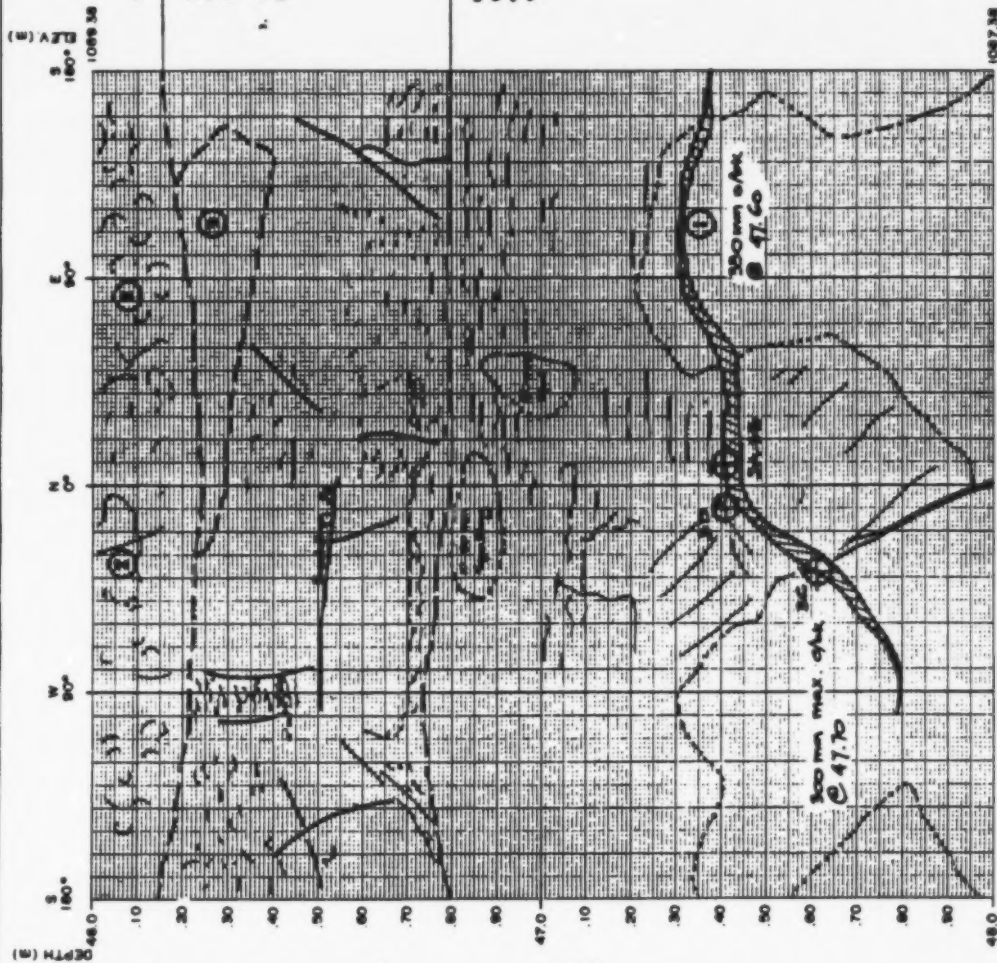
STRUCTURAL DETAILS

Joints: abundant, tight, steeply inclined, "stepped" appearance.

Fractures: short, sub-horizontal, very tight, parallel to contact.

1. Silty clay sand: maximum 50 mm thick, claystone fragments to a matrix of silty clay; low to medium plastic, dark gray; pieces cut to a thin, clay coated fracture; mill roots are thin and weak.

2. Spalling: 20 - 30 mm.



LITHOLOGICAL DETAILS

Silty claystone: continuous, shaly, slight linear contact.

Sandy siltstone: fresh, uniform with trough shaped cross bedding, bedding sets 50 mm long, medium brownish gray, very strong, tightly jointed.

3. Sandstone lenses: fresh, 20 - 30 mm trough shaped cross bedding, brownish gray, medium grained, very strong.

Claystone: fresh, dark brownish gray, weak to moderately strong, petrioid fissile. Fractures: vertical to sub-horizontal, smooth, curved, multi-directional, generally tight with some slitting and spalling.

Abaco

DEPARTMENT OF THE ARMY

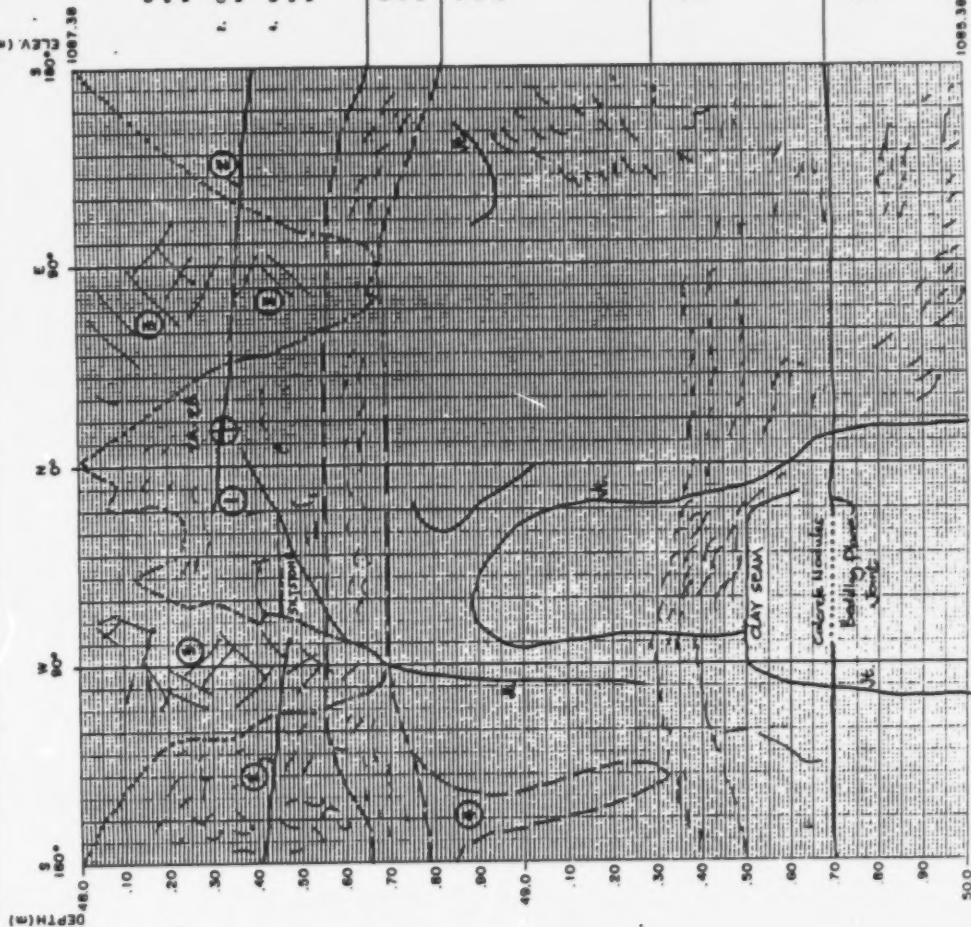
SHAFT 8707

SHEET 17 OF 23

LOGGED BY: H. HARTMAIER

DATE: SEPT. 12, 1966

STRUCTURAL DETAILS



1. Zone: 1 - 2 m, discontinuous, curved to undulating, slip clay; plastic, medium grayish green, soft, wet. Walls of zone are as strong as surrounding rock.
2. Brecciated: up to 200 m, spalling.

Joints in claystone: curved, rough, tight, clean, discontinuous.

Joints in sandy siltstone: undulating, smooth, tight, regular.

LITHOLOGICAL DETAILS

CLAYSTONE: fresh, medium grayish green, weak, extensive overprint, slaking, spalling, softened by water. Fractures are: sheared, slickensided, subvertical, curved.

3. Carbonaceous zone: diffuse, gradational contacts, 10 - 15 m thick.

4. CLAYSTONE: fresh, dark gray, part of zone carbonaceous claystone, may represent an old weathering profile on the siltstone surface, contacts tight, sharp.

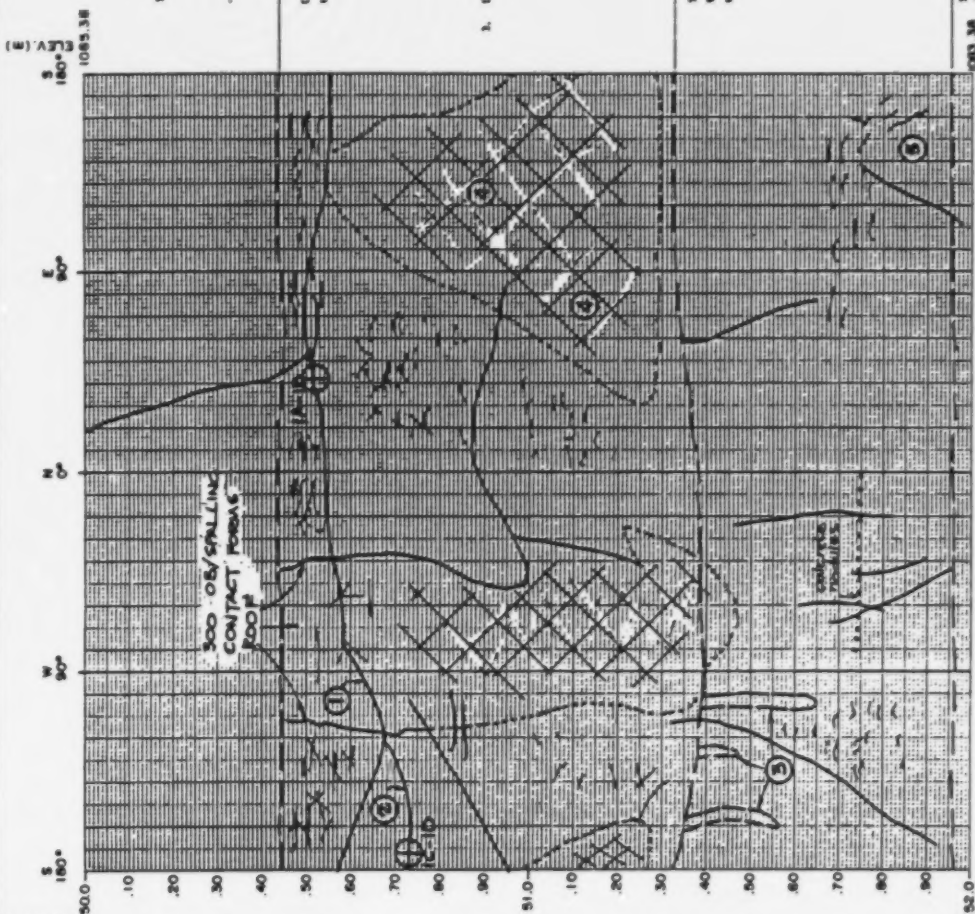
Carbonaceous CLAYSTONE: fresh, uniform, dark gray to black, weak, slightly jointed with short, continuous, irregular to curved fractures, local spalling and slaking.

SILTSTONE: fresh, uniform, massive, medium grayish green, strong to very strong, occasional calcareous nodules to 10 cm, tight joints.

CLAYE SILTSTONE: calcareous nodules to 10 cm, some clasts of hard siltstone: lens shaped, 50 - 100 cm.

Sandy SILTSTONE: fresh, trough shaped crest making limitations, medium gray to brownish green, very strong, scattered calcareous nodules to 10 cm, upper contact is tight and sharp.

LITHOLOGICAL DETAILS



fractures in siliques: curved, (top), clean, discontinuous, zones of short, irregular, curved fractures at base, 10 - 20 cm long.

Landry VILLAGE: as above.

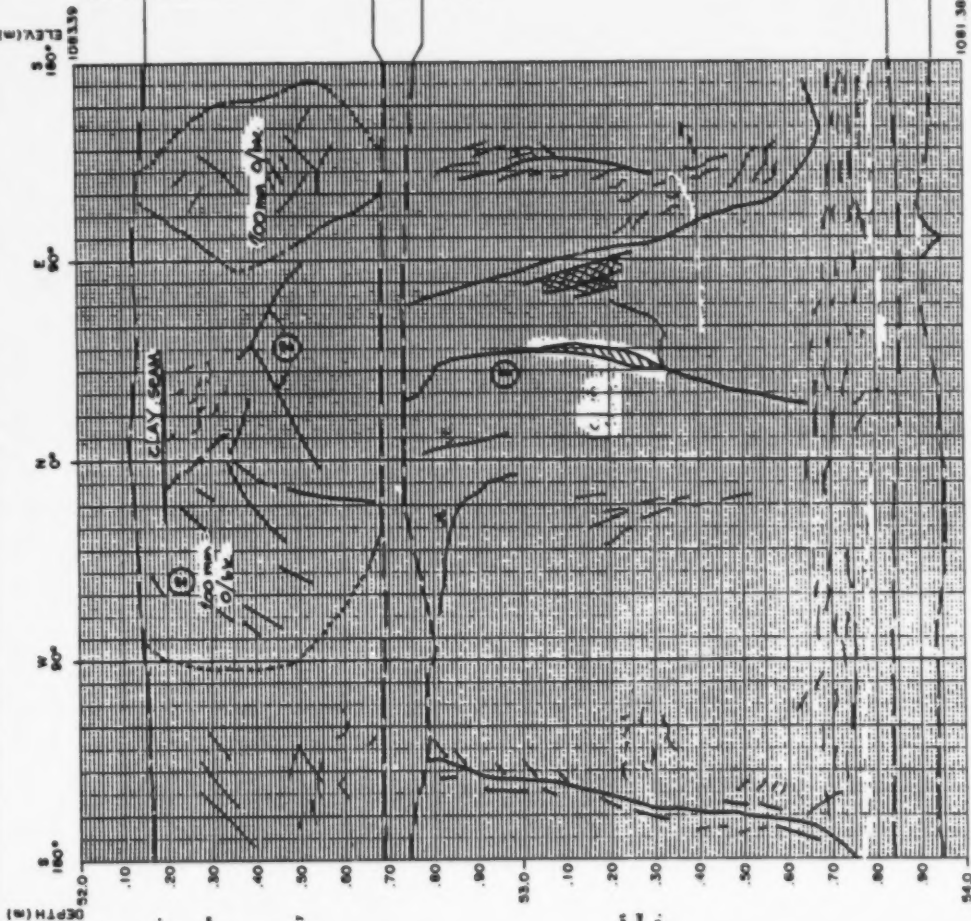
CLASSIFICATION: Fresh, uniform, dark grayish green, wet. Intense light, locally carbonaceous, viciated, multi-directional.

D. CLAVING: Fresh, dark gray, adjacent to sub-ventral fracture.

DESCRIPTION: Fresh, uniform, thickly bedded, very strong, unspotted, greenish gray to black; silicate nodules occur in bands and scattered, to 15 mm diameter.

Only CLA-VIOM: See description on next page.

STRUCTURAL DETAILS



Fractures in claystone: abundant, all on section perpendicular, slickensided surfaces are discontinuous.

1. Joint: unloading, comp. zone 5 m below 52.7% and 53.5%, from strike-slip, trending NE.

2. Slickensided fractures.

Joints and fractures: tight, generally close, occasionally basins with iron oxide.

Sub-vertical joints: unloading, tight, intersect compressional claystone and limestone in (indicated), curved, sub-vertical and sub-horizontal, tight fractures; adjacent sub-parallel fractures.

LITHOLOGICAL DETAILS

Silty claystone: fresh, uniform, medium grayish green, strong, abundant calcareous nodules to 10 mm, compressional failure on linear contact, beds contacts are tight, sharp.

Claystone: fresh, uniform grayish green, very weak, joints: multi-directional, curved, slickensided.

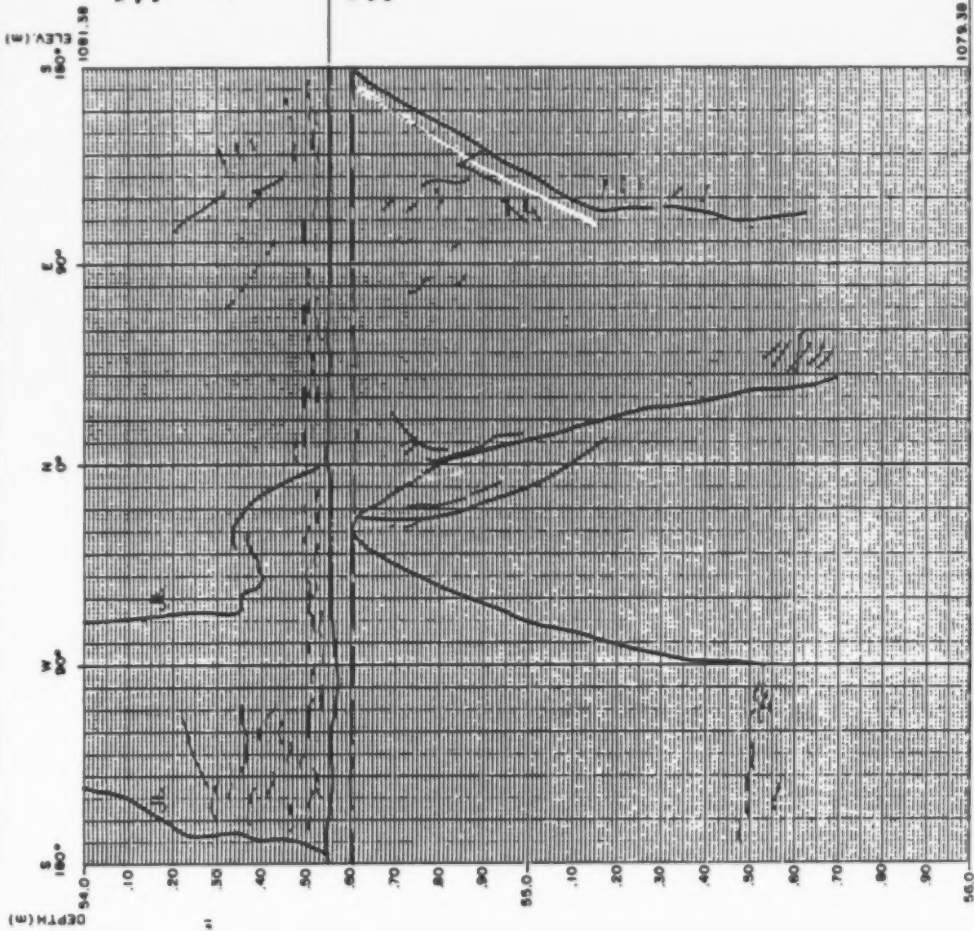
Clayey siltstone: gradational contact over 100 to 200 mm, poorly defined.

Siltstone to sandy siltstone: freshly jointed with iron oxide on joints, generally uniform, faint cross bedding lamination, medium brownish gray, very strong, tight joints.

Compressional claystone: fresh, black, moderately strong, contacts are sharp and tight.

1081.38

STRUCTURAL DETAILS



Fracture zone: closely spaced, curved, tight, sub-horizontal fractures near contact.

Joints: clean, curved to undulating, rough, tight.

LITHOLOGICAL DETAILS

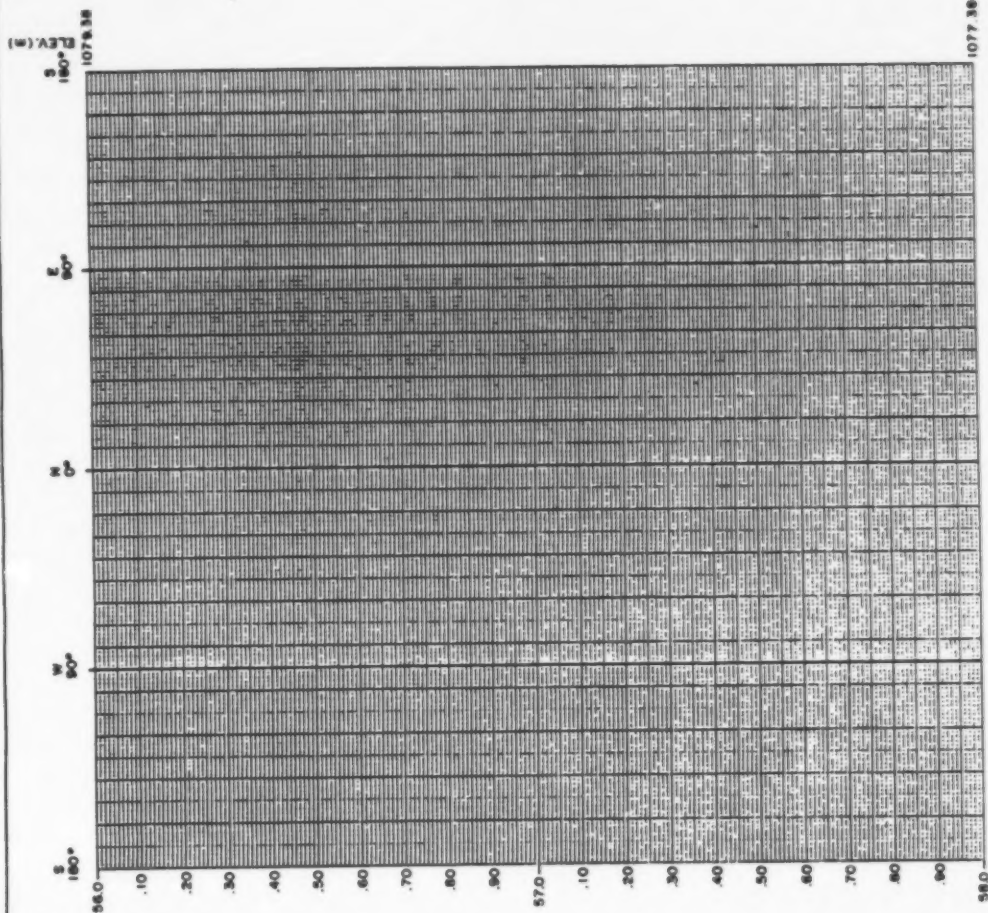
Unit: SILTSTONE to SANDSTONE: fresh, uniform, light bluish, medium grayish green, fine grained to medium grained, very strong, tight joints, lenses and masses of sandstone.

SANDSTONE: uniform, massive, slightly bluish, medium grayish green, fine grained, very strong, joints are tight, clean, some filled with calcite, scattered calcite nodules to 20 cm.

SILTSTONE: not logged lower than 55.90 m because shaft water level is 55.35

	SHEET 21 OF 23 LOGGED BY: H. HARTMANN DATE: SEPT. 14, 1966
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STRUCTURAL DETAILS



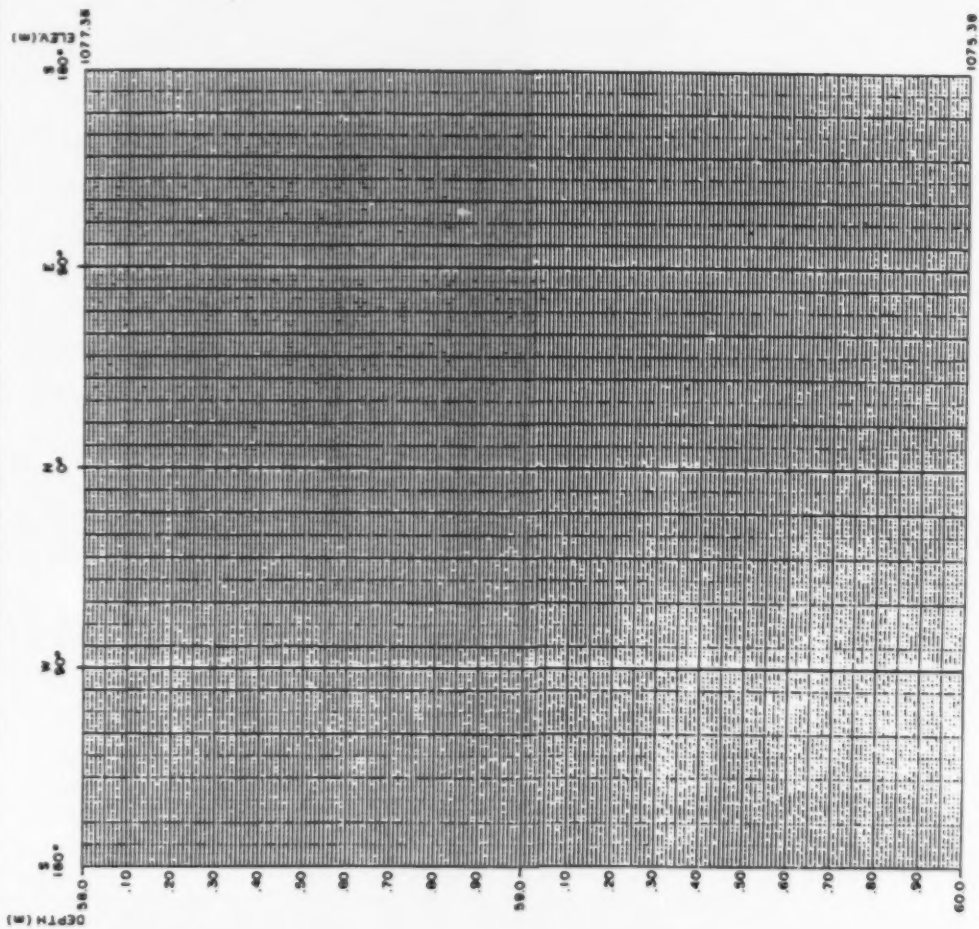
NOT
LOGGED

LITHOLOGICAL DETAILS

NOT
LOGGED

ADCO ☐ **UNO**
 COLLEGE POINT DRILL
 SHEET 3707
 SHEET 22 OF 23
 LOGGED BY : H. HARTMAIER
 DATE : SEPT. 14, 1986

STRUCTURAL DETAILS



NOT
LOGGED

LITHOLOGICAL DETAILS

NOT
LOGGED

ADCO	UNITED STATES
OILSHALE REVENUE DATA	
SHAFT 5707	
SHEET 23 OF 23	
LOGGED BY : H. HARTMAN	
DATE : SEPT. 14, 1966	

LOG FOR
EXPLORATORY SHAFT

D 14

PLATE B-236

OLDMAN RIVER DAM
SHAFT

LEGEND:



THIN DISCONTINUITY



THICK DISCONTINUITY



OVERBREAK ZONE

CORE SAMPLE LOCATION



CALCRETE NODULES



PHREATIC SURFACE

ABBREVIATIONS:

o/bk

overbreak

sst

sandstone

mcs

silty claystone

Jt

joint

bx

breccia

LITHOLOGICAL DETAILS

(1. 10-10, P) STATIC W.L. 6.00 below ground surface

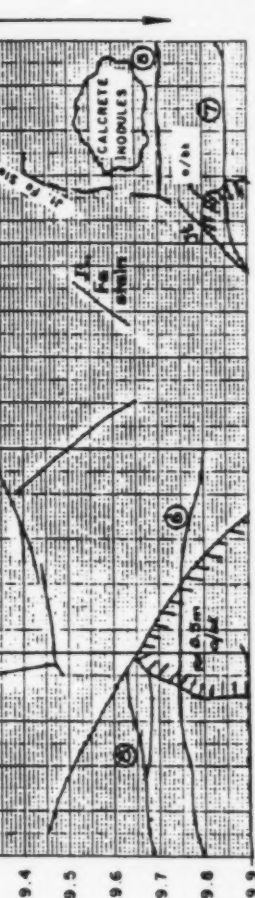
— bottom of center —

- STEM** - CLAVE BITTED; slightly to moderately woody, discolored along joints and bedding planes. If not coated, medium grayish green when fresh. Numerous strong scattered sclereite nodules.

Influence of water stress on leaf canopy - light distribution

Start of 'rotation' water inflow

SUBJECT - CLAY MINERAL: occurring together. Joints have to enter cutting.



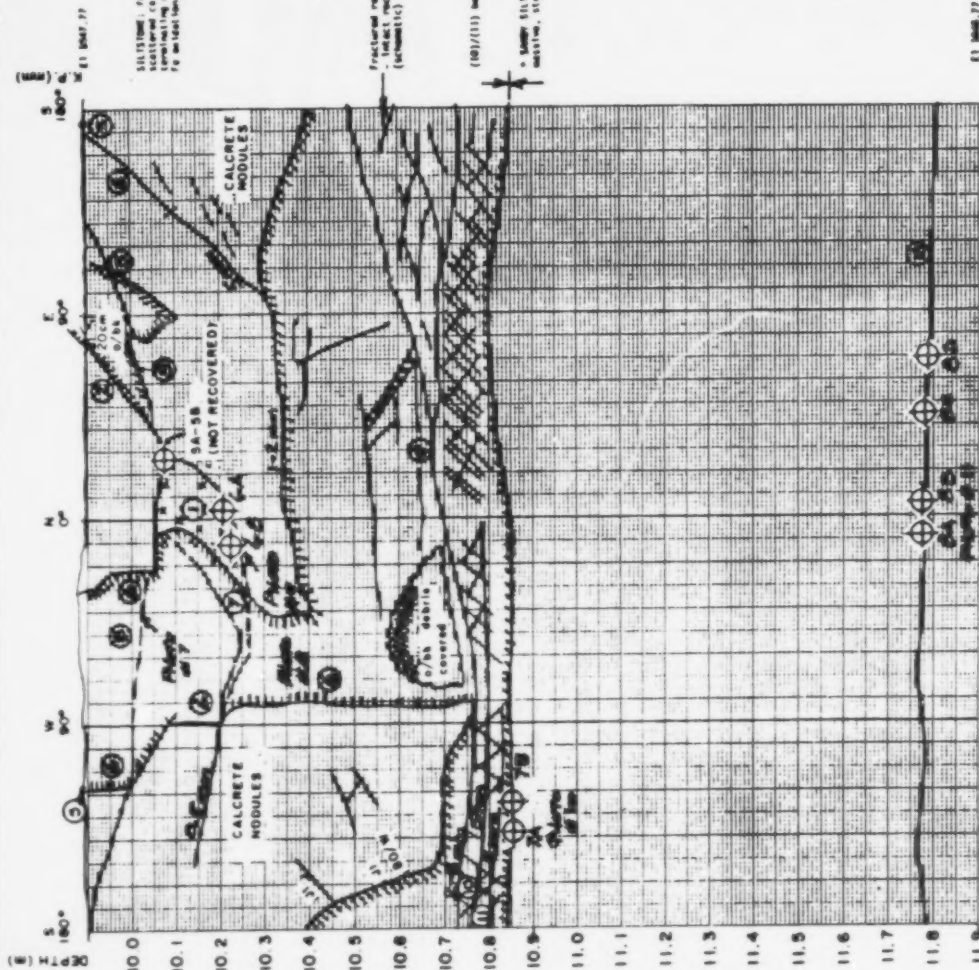
100777

STRUCTURAL DETAILS

1. Brecciated zone, approximately 100 m thick, light gray clay, clay-stiff, non-plastic.
2. Joint off-axis. From the clay-stiff, non-plastic zone, clay-stiff - may be related to or from drill cuttings.
3. Joint, off-axis. To outside staining, rough irregular, light.
4. Clay filler joint 5 m thick, bearing light.
5. 1-2 m clay seam, some sub-parallel 20 to 30 m long joints adjacent within 50 m.
6. Series of sub-vertical joints, bearing north-northeast, clay-stiff, rough, slightly, sub-parallel, from side of sub-parallel zone.
7. Within feature (1) above, approximately 50 m within joint with, with rocks visible approximately 10 - 20'.
8. On north west side becomes 2.5 m clay seam, from upper contact of brecciated zone on North East side, connects with (5) at South end.
9. 1-2 m clay seam at South end, surface inclined at 10° to 15° from vertical, clay-stiff, rough, slightly, laminated, fine, highly weathered in or from drill cuttings.
- 10, 11 2.5 m clay/silt seam, non-plastic.
12. Zone of weak, brecciated rock, below feature 10, 11, 12 m to very closely jointed and fragmented rock, 100 fragments, 100 fine matrix.
13. Bedding plane, light, 1-2 m silt filling, highly eroding, containing scattered pebbles of brecciation, 100 x 100 m.

LEGEND

	THIN DISCONTINUITY
	THICK DISCONTINUITY
	CORE SAMPLE LOCATION
	CALCRETE MODULES
	POROSITY SURFACE
	OVERTURN
	FAULT
	SILT CLAYSTONE
	JOINT
	BRECCIATED
	BEDDING PLANE
	MODERATELY WEATHERED
	FRESH



DEPT H (W) 180° 90° 0° 90° 180°
E (m) 180° 90° 0° 90° 180°
E (m) 180° 90° 0° 90° 180°

10/11/1988. Fresh, medium granitic grey, moderately strong, scattered calcareous nodules, sub-vertical joints, containing an clay coated bedding planes, slight pitting.

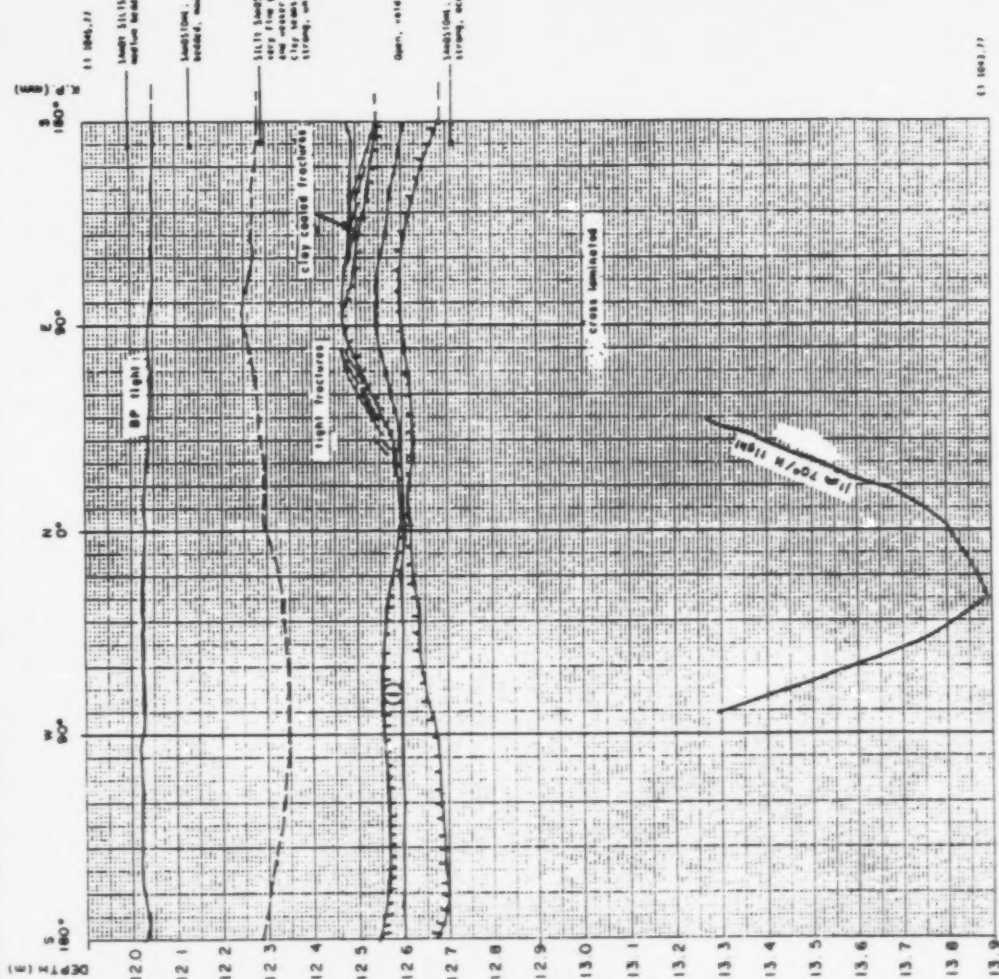
Fractured rock lenses
- intact rock with 10-30 mm thick brecciated zones (calcrete?)

(100/111) becomes lost to brecciated zone

* Sample 55/111, medium granitic grey, very fine grained, massive, strong, scattered calcareous nodules to 10 mm

E (m) 180° 90° 0° 90° 180°

LITHOLOGICAL DETAILS



Open leading plane, exhibiting, approximately 45 degrees, 10 m in back of nose up to converge with 45 degrees in ground, patches of white wall much less than 10-15 m in front, surface coated with fine white sand deposits, 188 days, 278 lit, 550 fmg (medium sand). Probably open or not but natural drifting washed out. Open beyond 500 m from shelf.

00175118

[illegible]

About
 OLDMAN'S NEWSPAPER
 SH-87-D14
 SHEET 3 OF 5
 LOGGED BY M HARTMAIER
 DATE AUG. 9, 1987

LITHOLOGICAL DETAILS

1000

Amblyopis 1906, light brownish gray, sometimes greenish.

60557

1. *Staphylococcus aureus*
 2. *Escherichia coli*
 3. *Salmonella enteritidis*
 4. *Streptococcus pneumoniae*
 5. *Haemophilus influenzae*
 6. *Neisseria meningitidis*
 7. *Clostridium botulinum*
 8. *Campylobacter jejuni*
 9. *Listeria monocytogenes*
 10. *Yersinia enterocolitica*
 11. *Shigella flexneri*
 12. *Legionella pneumophila*
 13. *Mycobacterium tuberculosis*
 14. *Coccidioides immitis*
 15. *Histoplasma capsulatum*
 16. *Cryptosporidium parvum*
 17. *Toxoplasma gondii*
 18. *Trichinella spiralis*
 19. *Ascaris lumbricoides*
 20. *Strongyloides stercoralis*
 21. *Enterobacteriaceae*
 22. *Gram-negative bacilli*
 23. *Gram-positive cocci*
 24. *Gram-negative bacilli*
 25. *Gram-positive bacilli*
 26. *Gram-negative bacilli*
 27. *Gram-positive cocci*
 28. *Gram-negative bacilli*
 29. *Gram-positive bacilli*
 30. *Gram-negative bacilli*
 31. *Gram-positive cocci*
 32. *Gram-negative bacilli*
 33. *Gram-positive bacilli*
 34. *Gram-negative bacilli*
 35. *Gram-positive cocci*
 36. *Gram-negative bacilli*
 37. *Gram-positive bacilli*
 38. *Gram-negative bacilli*
 39. *Gram-positive cocci*
 40. *Gram-negative bacilli*
 41. *Gram-positive bacilli*
 42. *Gram-negative bacilli*
 43. *Gram-positive cocci*
 44. *Gram-negative bacilli*
 45. *Gram-positive bacilli*
 46. *Gram-negative bacilli*
 47. *Gram-positive cocci*
 48. *Gram-negative bacilli*
 49. *Gram-positive bacilli*
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 58. *Gram-negative bacilli*
 59. *Gram-positive cocci*
 60. *Gram-negative bacilli*
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 62. *Gram-negative bacilli*
 63. *Gram-positive cocci*
 64. *Gram-negative bacilli*
 65. *Gram-positive bacilli*
 66. *Gram-negative bacilli*
 67. *Gram-positive cocci*
 68. *Gram-negative bacilli*
 69. *Gram-positive bacilli*
 70. *Gram-negative bacilli*
 71. *Gram-positive cocci*
 72. *Gram-negative bacilli*
 73. *Gram-positive bacilli*
 74. *Gram-negative bacilli*
 75. *Gram-positive cocci*
 76. *Gram-negative bacilli*
 77. *Gram-positive bacilli*
 78. *Gram-negative bacilli*
 79. *Gram-positive cocci*
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 81. *Gram-positive bacilli*
 82. *Gram-negative bacilli*
 83. *Gram-positive cocci*
 84. *Gram-negative bacilli*
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 88. *Gram-negative bacilli*
 89. *Gram-positive bacilli*
 90. *Gram-negative bacilli*
 91. *Gram-positive cocci*
 92. *Gram-negative bacilli*
 93. *Gram-positive bacilli*
 94. *Gram-negative bacilli*
 95. *Gram-positive cocci*
 96. *Gram-negative bacilli*
 97. *Gram-positive bacilli*
 98. *Gram-negative bacilli*
 99. *Gram-positive cocci*
 100. *Gram-negative bacilli*

all subjected to the I. O. O. F. test, and has gained, even limited, some considerable satisfaction, very strong, active.

22 1000 22

Abeno

HOTEL DEL MONTE CARLO

KRAFT SM-87-014

SHEET 4 OF 5

LOGGED BY: H HARTMAN

DATE AUG. 9, 1987

LITHOLOGICAL DETAILS



1.  $y = \sin(x)$
 2.  $y = \sin(x)$
 3.  $y = \sin(x)$
 4.  $y = \sin(x)$
 5.  $y = \sin(x)$
 6.  $y = \sin(x)$
 7.  $y = \sin(x)$
 8.  $y = \sin(x)$
 9.  $y = \sin(x)$
 10.  $y = \sin(x)$

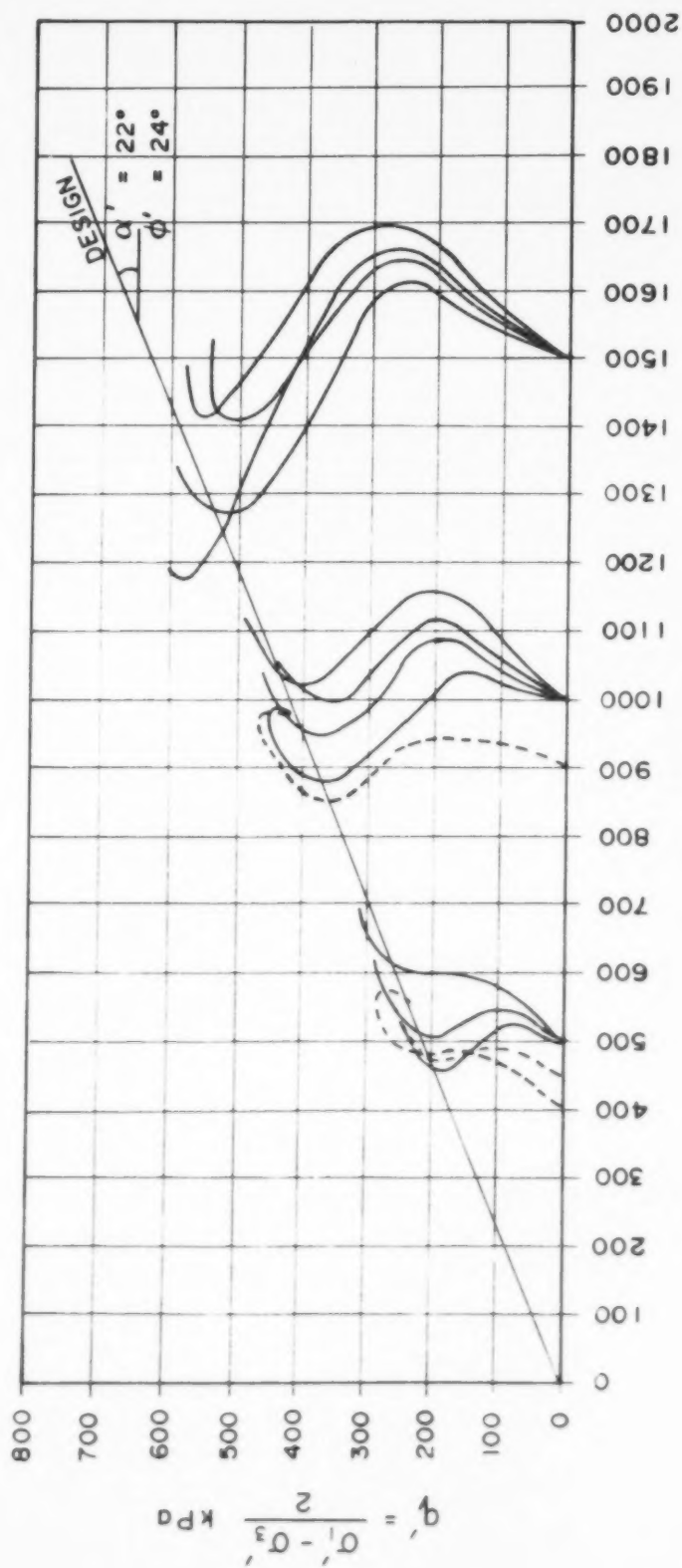
ing to kill on average four people a day.

Importation de 100 tonnes P.F. 50.000.000 en deux lots de 50 tonnes

100

19 4400-97

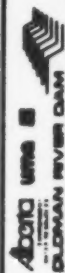
Abana
SHEEP 3 OF 3
LOGGED BY: M. HARTWATER
DATE: AUG. 9, 1987



ISOTROPICALLY CONSOLIDATED
UNDRAINED CYCLIC AND STATIC
TRIAXIAL TESTS - COMPACTED TILL

LEGEND:

— STATIC
--- CYCLIC



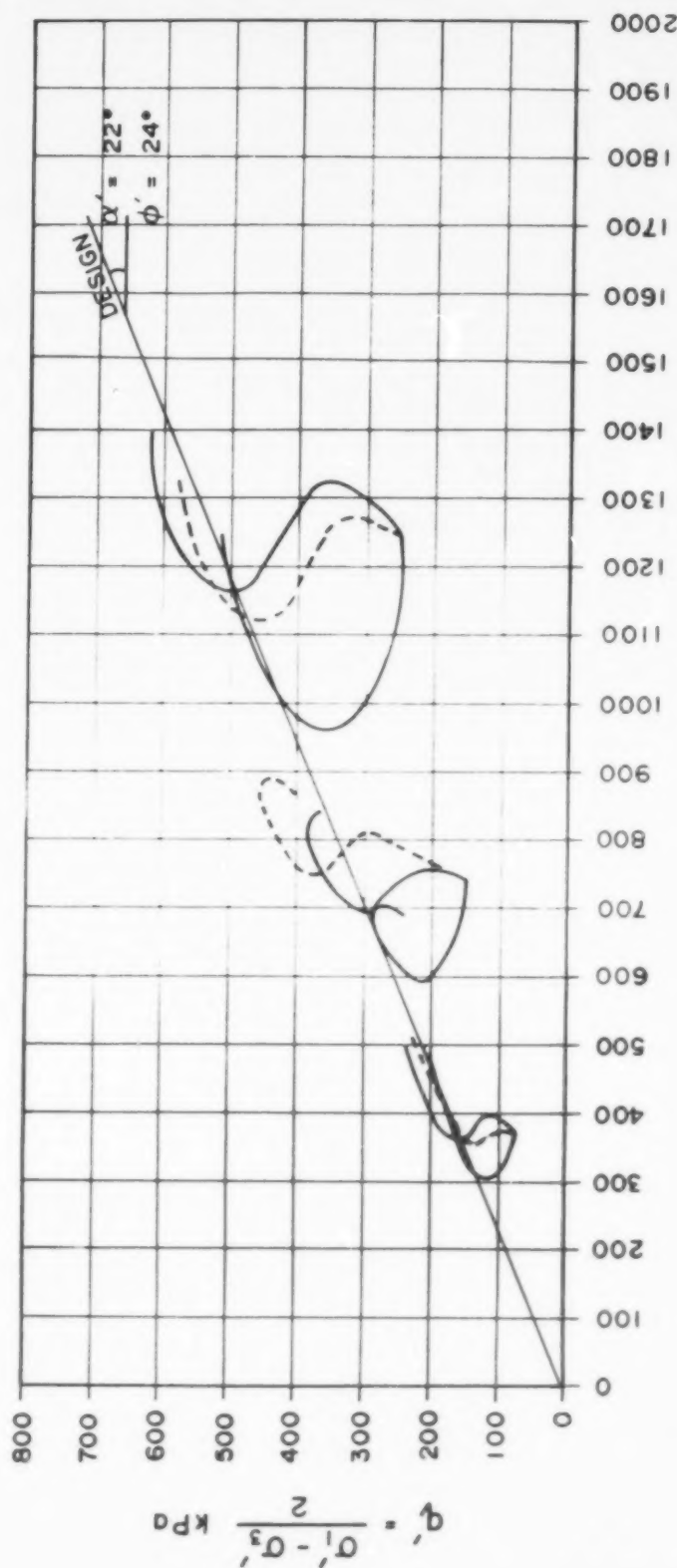
CYCLIC AND STATIC
TRIAXIAL TESTS
COMPACTED TILL - I

PLATE B-237



CYCLIC AND STATIC
TRIAxIAL TESTS
COMPACTED TILL -2

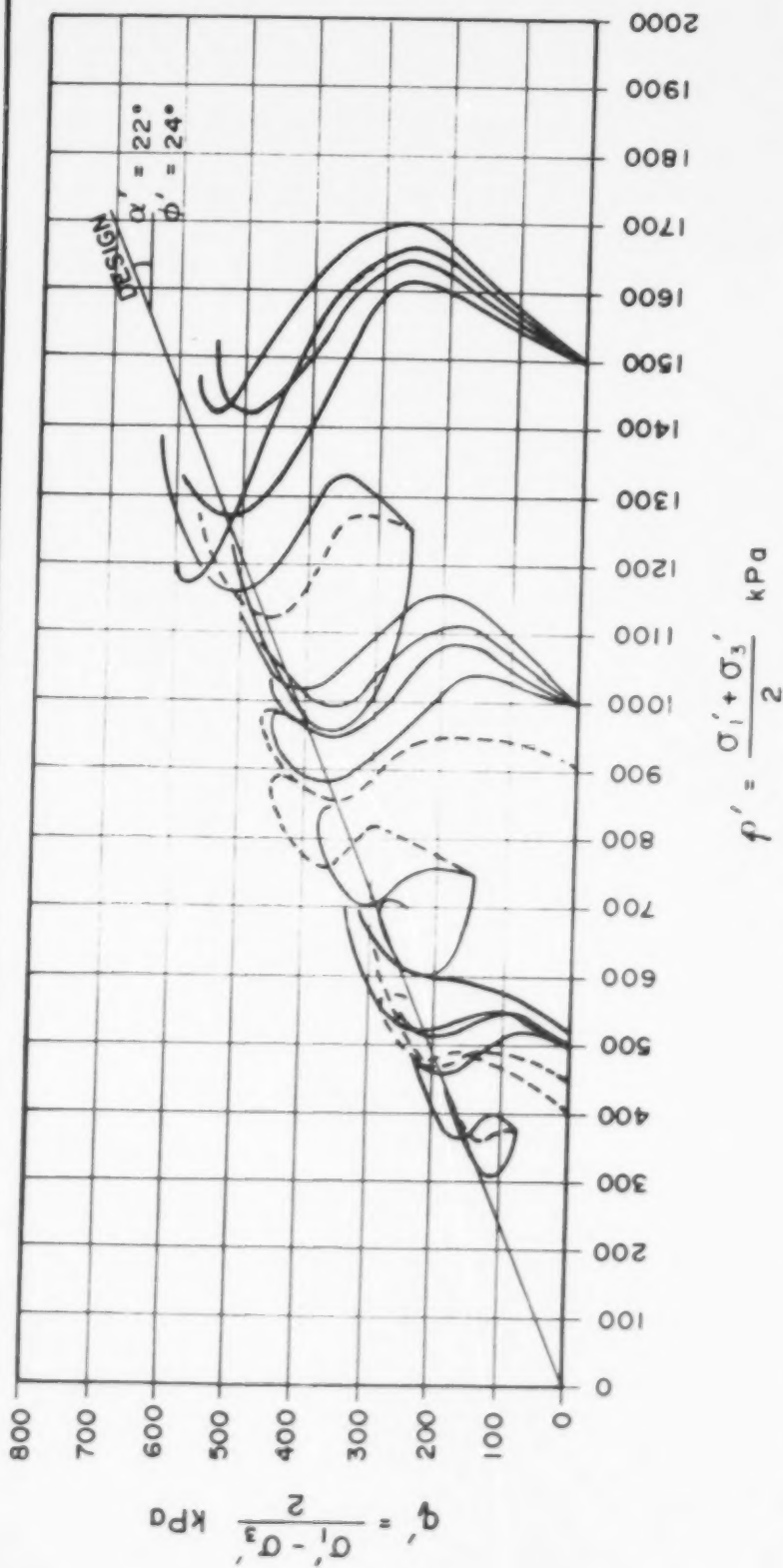
PLATE B-238



ANISOTROPICALLY CONSOLIDATED
UNDRAINED CYCLIC AND STATIC
TRIAxIAL TESTS - COMPACTED TILL

LEGEND:

— STATIC
--- CYCLIC



ISOTROPICALLY AND ANISOTROPICALLY
CONSOLIDATED UNDRAINED CYCLIC
AND STATIC TRIAXIAL TESTS -
COMPACTED TILL

LEGEND:

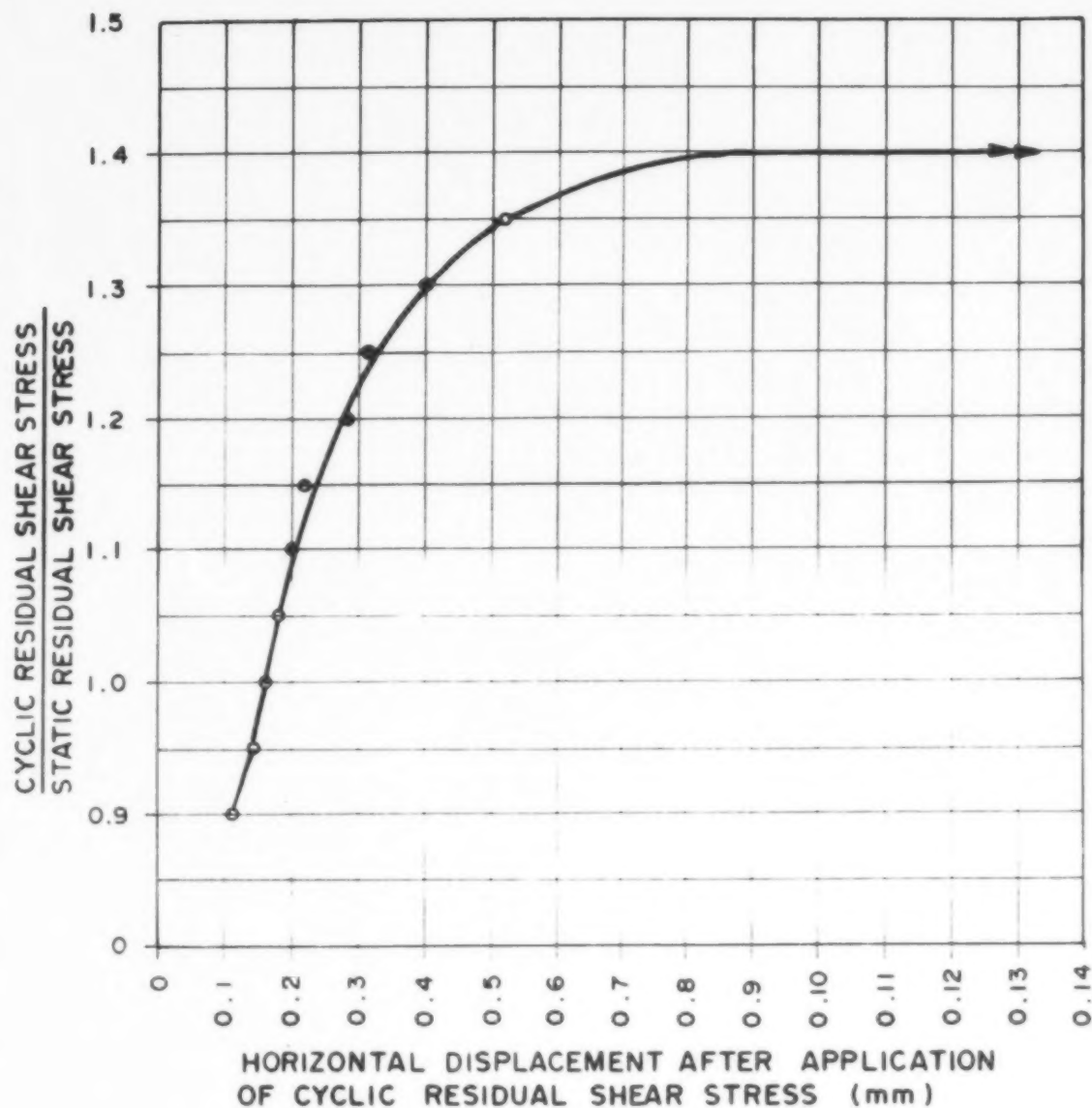
—— STATIC

---- CYCLIC



CYCLIC AND STATIC
TRIAxIAL TESTS
COMPACTED TILL-3

PLATE B-239



CYCLIC DIRECT SHEAR TEST RESULTS
FOR SEAM FROM
SHAFT NO. SH-85-D95 - SAMPLE IIA
(10 CYCLES PER EACH TEST)

**MAPS
NOT
FILMED**

**CARTES
OMISES**